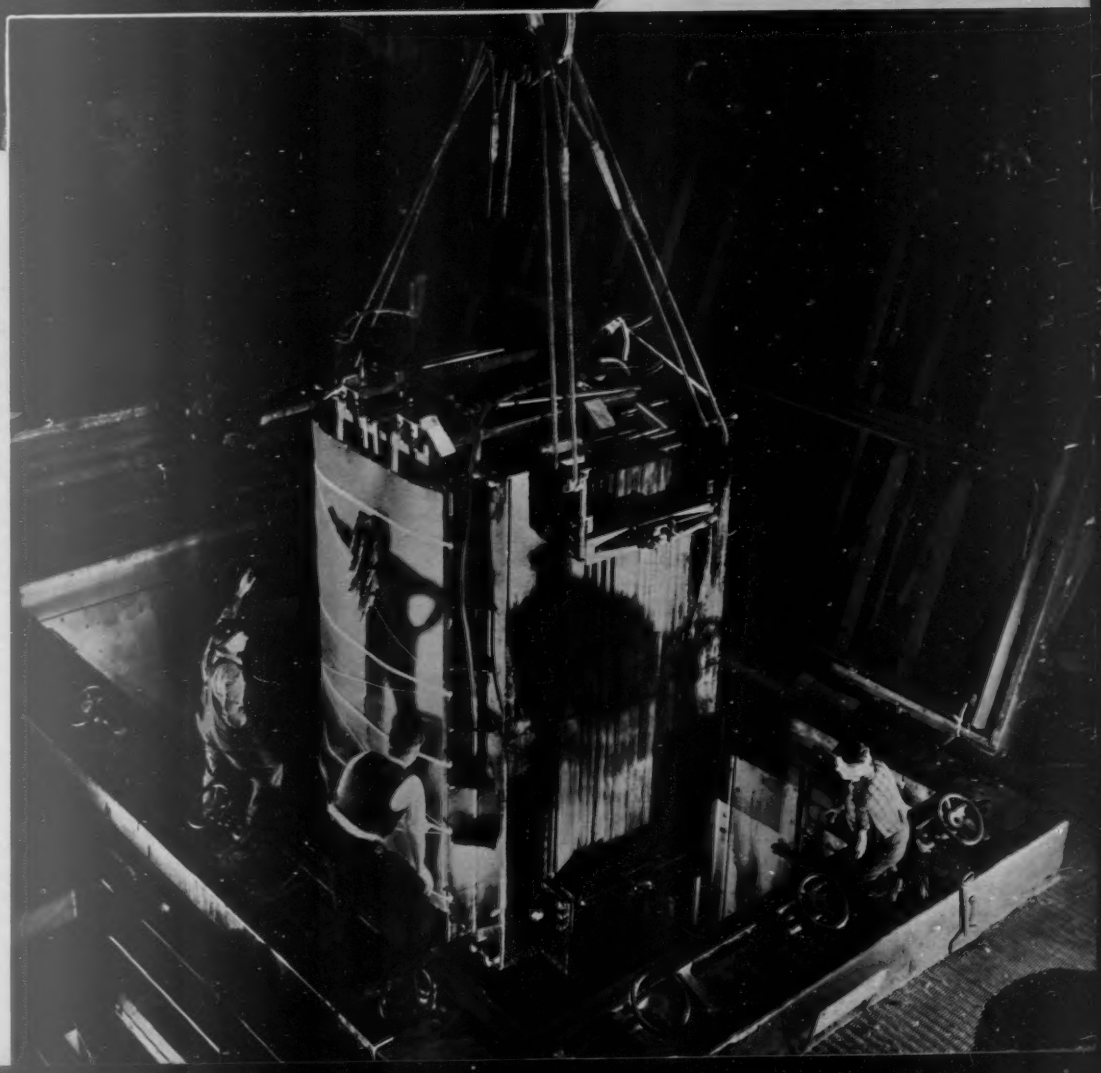
ALLIS-CHALMERS

ELECTRICAL REVIEW

March • 1941



Core and coils of a 30,000 kva. single-phase transformer being lowered into the vacuum tank. For story see page 20.

HOW TO GET INERT GAS PROTECTION WITH LESS MAINTENANCE!

LOW-COST MAINTENANCE OF OIL WITH the OIL-SEALED System is only one of the extra value features this eastern utility obtained when they installed these three 10,410 kva Allis-Chalmers Power Transformers with Load-Ratio-Control.

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IF YOU ARE like many utility engineers who recognize the advantages of inert gas protection but wish to avoid the high maintenance costs that high-pressure inert gas systems involve, here's money-saving news for you!

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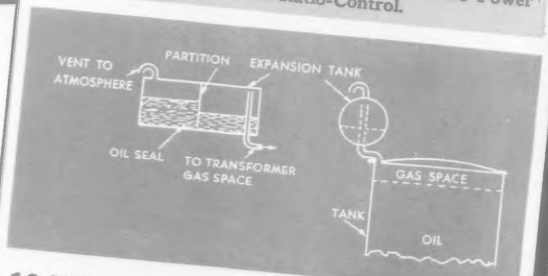
For the inert gas system on Allis-Chalmers Power Transformers maintains the quality of insulating oil with no pressure reducing valves to adjust or replace . . . no mechanical moving parts to get out of order or wear out . . . no chemicals to handle. All you do is blow out the oxygen in the gas space . . . place the transformer in service . . . and forget about oil sludging.

Once you've given it a trial you'll see why operators call it the "automatic system that operates without attention." And you'll like the low operating pressures (almost always less than one pound per square inch) that minimize oil seepage . . . eliminate constant nitrogen replacement.

To find out how you can put Allis-Chalmers superiority in transformer engineering to work for you, call the district office near you or write for Bulletin 1182.



16 YEAR SERVICE RECORD OF FIRST INERT GAS SYSTEM OUTSTANDING — A TRUE CASE HISTORY ON THE OIL-SEALED SYSTEM

IN 1923 Allis-Chalmers installed the OIL-SEALED System as the first commercial application of any inert gas protection to eighteen 15,000 kva power transformers for an eastern utility. At that time the oxygen was not initially blown out as is the practice today. Yet after three years of operation . . . with absolutely no maintenance or inspection . . . the average oxygen content in the gas space measured less than 2.4% in every one of the 18 units . . . oil oxidation was negligible. ***And today . . . over 16 years later . . . those transformers are still giving maintenance-free service protected by the exclusive OIL-SEALED Inert Gas System!*** A 1221

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ELECTRICAL REVIEW

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SAND IN THE DEFENSE MACHINERY

J. P. Barton, **Manager, Bureau of Electrical Sheet Sales**

CARNEGIE-ILLINOIS STEEL CORP. • PITTSBURGH, PENNSYLVANIA

Sand in gears means sabotage . . . in steel, improved magnetic properties. Silicon steel is the heart of electrical apparatus . . . contributing to efficient production, distribution, and consumption of power . . . the life-blood of the defense program.

● About forty years ago, Sir Robert Hadfield discovered that the addition of the element silicon to steel, in amounts up to four or five percent, improved the magnetic properties of low carbon steel sheets to such an extent that hysteresis and eddy losses were greatly reduced and permeability improved. As this discovery occurred in the period when the possibilities of alternating-current systems were being exploited, it gave an added impetus to the more efficient use of such systems by providing magnetic materials which were superior to those previously available.

During the first decade of the present century, the development of silicon steels in sheet form was undertaken by several mills in this country, as well as in Europe, so that by the second decade various grades, each having definite and improved properties, were being produced by refinements of the original practice. Since then, more grades have been added by research and by the development of improved mill practices, and lower core losses have been realized.

In Fig. 1 the core loss improvement since 1905 is shown for sheets 0.014 in. (29 gauge) thick, of lowest core loss, at 60 cycles, ten kilogausses, amounting to a reduction of about 65 percent. Similar large reductions in other grades and thicknesses have greatly aided the engineer to design transformers and rotating machines of larger capacities and higher efficiencies at a lower cost, thereby contributing largely to the continued increase in power production and consumption.

Silicon increases the electrical resistivity of low carbon steels (under 0.10 percent carbon), as shown in Fig. 3, thus reducing the losses due to eddy currents. The combination of correct mill processing and heat treatment, together with the addition of silicon to the steel, also improves permeability in the medium and lower flux densities, resulting in lower hysteresis losses. As the sheet thickness affects eddy current losses, practically all sheets produced today are within the range of 0.025 in. to 0.014 in. thick. For rotating machines of low and medium efficiency, sheet thicknesses of 0.0250 in. and 0.0185 in. predominate in the low and medium silicon contents (0.25 to 2.75 percent). For higher efficiency machines, thicknesses of 0.0185 in. and 0.014 in. are used in the silicon range (2.75 to 4.50 percent) with 0.014 in. thick sheets being extensively used in 60 cycle transformers.

The several commercial grades and their guaranteed maximum core losses for various thicknesses are shown in the table, Fig. 2. Core losses are measured in accordance with the Epstein test, this procedure

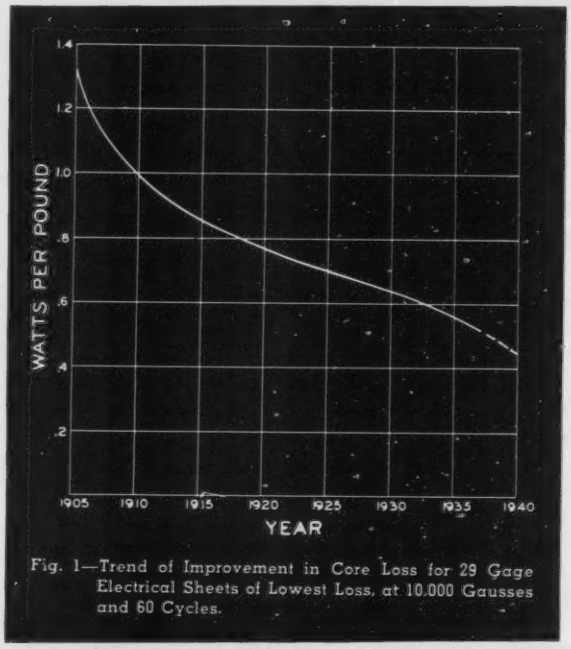


Fig. 1—Trend of Improvement in Core Loss for 29 Gage Electrical Sheets of Lowest Loss, at 10,000 Gausses and 60 Cycles.

AT LEFT: Teeming a ladle of steel into ingot molds.

Epstein Test According to A. S. T. M. Standard Method A-34

	Electrical Steel Sheet Gage Number							
GRADE	29	28	27	26	25	24	23	22
Armature	1.30	1.38	1.46	1.55	1.75	1.98	2.23	2.50
Electrical	1.17	1.23	1.29	1.35	1.50	1.70	1.94	2.17
Motor	1.01	1.05	1.09	1.14	1.22	1.30		
Dynamo	.82	.86	.90	.94	1.02	1.10		
Transformer 72	.72	.76	.80	.83	.90	.97		
Transformer 65	.65							
Transformer 58	.58							
Transformer 52	.52							

Watts per Pound at 60 Cycles and 10,000 Gausses

Fig. 2 — Electrical Sheets Guaranteed Maximum Core Losses

having been established by the A. S. T. M. in its Standard Method A-34, which is accepted throughout this country and is well recognized abroad. A typical core loss testing laboratory is shown in Fig. 4.

Silicon steel manufacture

In the present manufacture of silicon steel sheets, production control starts with the quality of the raw materials entering the open hearth furnaces. The iron charge can be either hot, such as molten iron from a blast furnace (see Fig. 5) or cold, such as pig iron and selected scrap. Furnaces ranging in capacity from 30 to 100 tons are used, with the charge being melted and refined in eight to 12 hours.

The open hearth heats are tapped into large ladles to which the silicon is added and the resulting alloy poured into ingots (see page 4). After the moulds are removed (see Fig. 6), the ingots are placed in soaking pits where they are heated to a uniform temperature prior to rolling into slabs or sheet bars (see Fig. 7). From this point on, several courses can be taken in converting silicon steel into finished sheets having the required magnetic quality.

The original manufacturing procedure, followed for years and still widely used, involves the hot rolling of sheets from sheet bar. These bars range in width from eight to 18 inches, with the bar length slightly greater than the width of the sheet, the bar thickness determining the sheet length. The bars are heated and rolled part way to sheet size, producing what is known as a breakdown. At this stage, a number of breakdowns are assembled into a pack, which is reheated and rolled to required length and thickness. Each breakdown may produce one or two sheets, depending upon the final sheet thickness and size.

Further treatment

After rolling, the pack is opened and the sheets separated, sheared to required size, and further processed with such treatments as cold rolling, normalizing, pickling and annealing, depending upon the grade or silicon content. All sheets receive a final heat treatment or annealing to establish the required magnetic properties.

In the annealing operation the sheets are stacked on a base and covered with an annealing hood. Sealing is effected by peripheral immersion in sand or other sealing mediums. Charges usually range between 15 and 20 tons and require from six to 14 days to pass through the annealing cycle. Temperatures range from about 1350 to 2000 F, depending upon the silicon content. High silicon transformer sheets receive the longest processing, usually being annealed in electrically heated furnaces at high temperatures, with the heating and cooling cycle requiring as long as two weeks. Slow cooling is necessary to assure flat sheets of uniform, good quality.

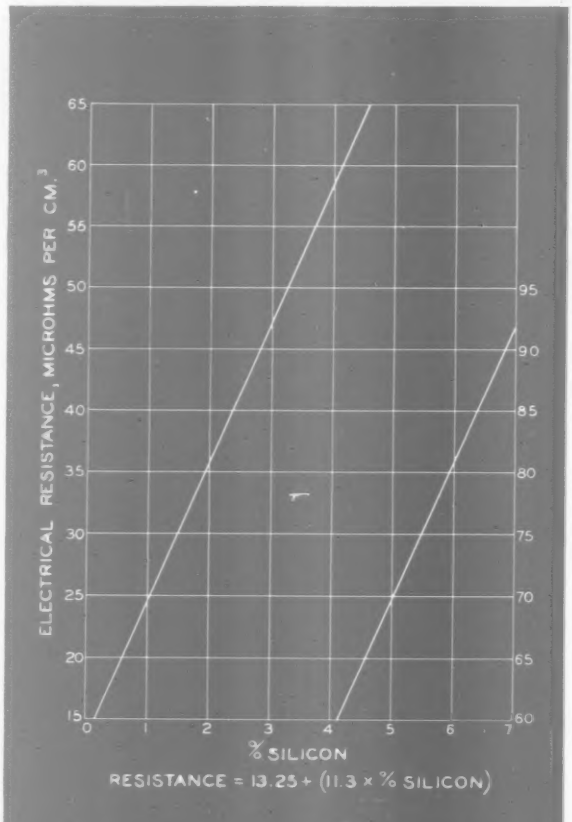


Fig. 3 — Silicon Content Versus Electrical Resistance of Silicon Steel Sheets for Electrical Purposes.

Fig. 4 — A typical laboratory for testing the magnetic quality of silicon steel sheets for electrical purposes.

Fig. 5—After leaving the blast furnace, a ladle of molten iron is poured into an open hearth furnace for refining to steel.

After annealing, the charge is divided into lifts, each weighing from 5000 to 8000 lb. Each sheet in a lift is inspected for quality, and sheets are taken at random throughout the lift for testing to determine core loss and other properties. Each lift is given an identification number, with the tested core loss for that lift associated with the lift number.

In general, the higher the silicon content and the lower the core loss, the greater is the production cost due to processing and the greater care necessary to assure attaining the required properties.

New methods introduced

With the advent of continuous hot and cold reduction mills in recent years, additional methods became available for producing flat rolled silicon steels in coils which could be cut into sheets and finished, or finished in coiled form.

The new continuous hot mills take slabs of the proper size, reheated after having been carefully prepared, and roll them in a continuous operation into long strips, ranging from 0.070 in. to 0.100 in. thick (see Figs. 8 and 9). This strip is either coiled as it

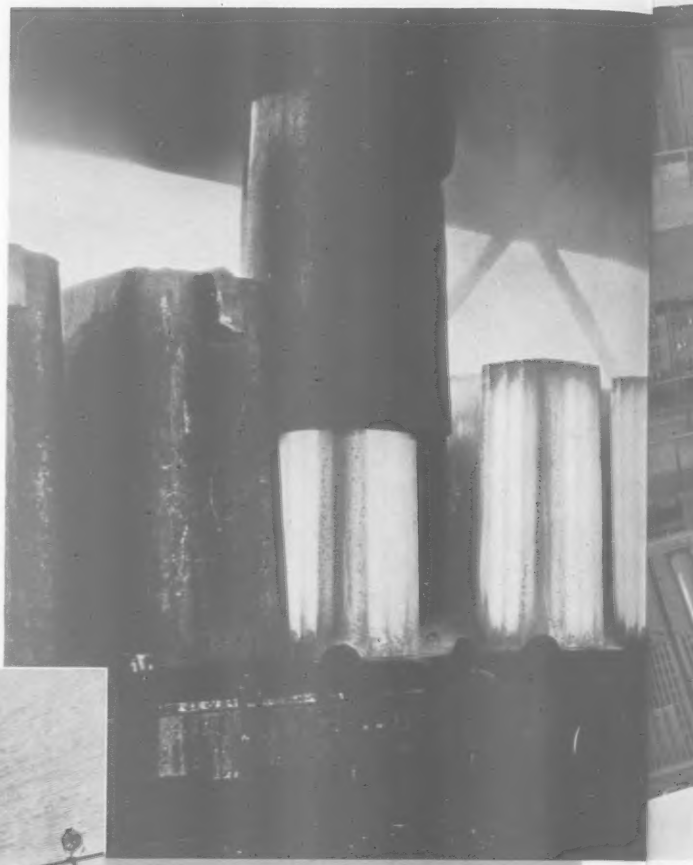


Fig. 6 — Ingots are stripped of their molds after which they are placed in soaking pits.

Fig. 7 — Rolling a uniformly heated ingot to suitable size for producing slabs or sheet bars.

Fig. 8—A reduction unit of a continuous hot process strip mill through which is passing a length of hot steel. In thickness it is intermediate between the slab (4 to 6 in.) and the finished strip (0.07 to 0.10 in.).

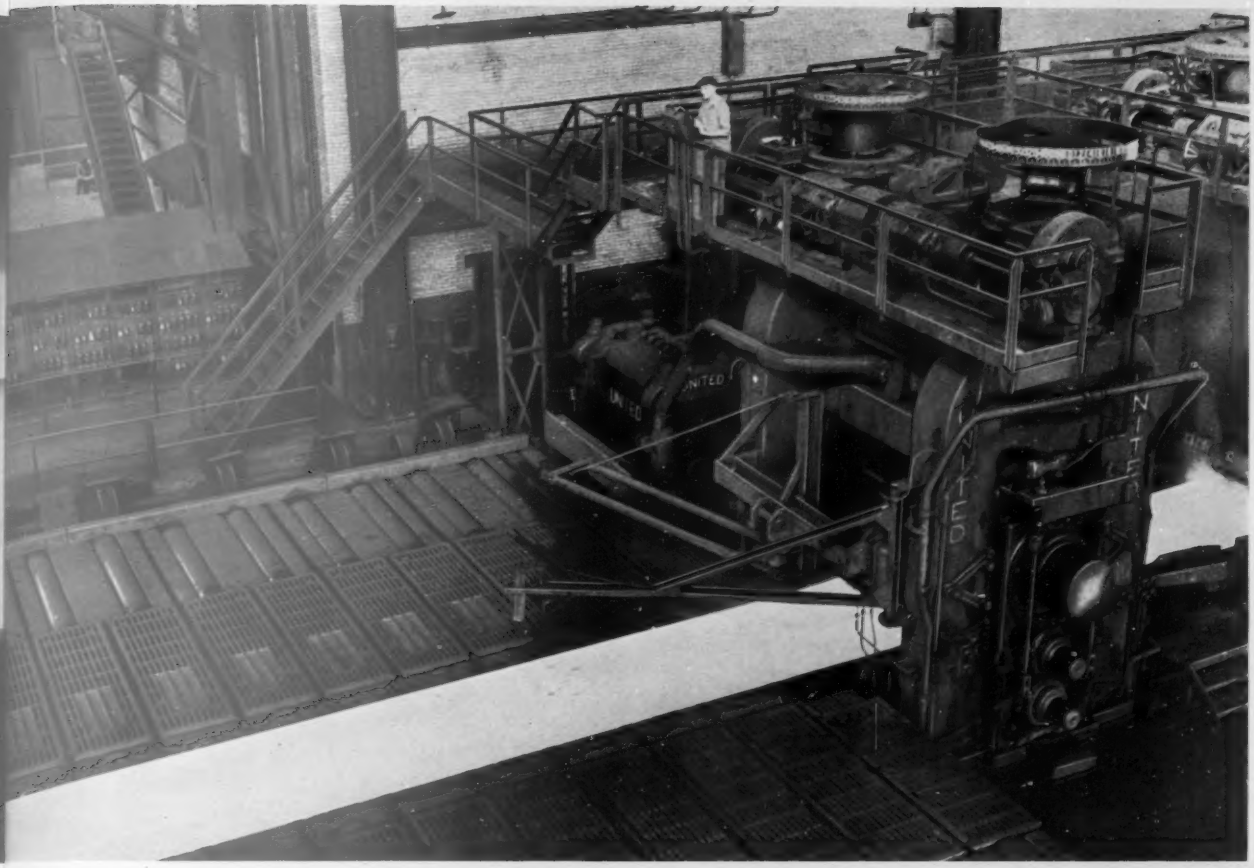


Fig. 9—The last reduction unit of a continuous hot strip mill, showing the strip emerging at the finished thickness — 0.07 to 0.10 in.

leaves the mill or cut into sheets, as desired, by flying shears. From this point on, there are two finishing procedures.

In one case, the sheets are assembled into packs, reheated, and the packs rolled down to required size and thickness in single-stand hot mills, as is done when sheet bar is used. Following this operation, the procedure is the same as previously described.

In the other case, the practice is to take the hot rolled strip in coils for further processing. The strip is pickled to remove the surface oxides resulting from hot rolling and then is cold reduced to required thickness, either with or without intermediate heat treatments. From this point on, various combinations of heat treating, annealing and additional slight cold reduction or temper rolling, and slitting to width are employed, coupled with a final heat treatment through a continuous annealing furnace to establish final quality.

The resulting product, in thicknesses from 0.014 in. to 0.025 in. and widths up to about 36 in., can then be shipped either in coils or cut into sheets or strips. The production of coiled strip under 12 in. wide was first developed, while the production of sheets in coils over 12 in. wide followed later.

From a consumer's viewpoint, in some cases it is more economical to use coils than sheets, as, for example, where large numbers of small laminations for small motors or transformers are produced daily, permitting high press speeds. For large laminations, which are usually special for each design and where press equipment is not designed to use coils, sheets usually prove more economical.

The next ten years will undoubtedly show continued improvement in the general quality of silicon steel, especially in the low core loss grades for transformers, through the application of the cold reduction processes. These improvements will make it possible for the engineer to accomplish design features difficult at present, just as present-day silicon steels offer much greater advantages than those of ten to 20 years ago. Without much question, it can be said that silicon steel is the heart of electrical apparatus and that its high quality during recent years has contributed greatly to the efficient production, distribution, and consumption of electric power.

WITH OR WITHOUT

F. C. DeWeese, **General Engineer**

CAROLINA POWER AND LIGHT CO. • RALEIGH, NORTH CAROLINA

Transmission lines can be had with or without . . . phase control. Here a more comprehensive method of calculating transmission line performance and efficiency unexpectedly proves lagging power factor may be desirable.

● An electrical transmission circuit may be a line supplying load at one end and having only one source of power supply. Or it may be a part of a transmission network having two or more sources of power supply. In either case, the line is considered in terms of its length in miles, and this physical length is primarily of value as a basis for determining the electrical length of the line. The electrical length of a transmission circuit is a function of its impedance which must be known before a transmission line problem can be solved.

Methods used in calculating the performance of short lines will not give the same degree of accuracy when applied to the solution of long line problems. This is because short lines have negligible capacitance, and as a result the line charging current is also negligible. On the other hand, for lines of any considerable length the effect of capacitance must be taken into account, or the calculated results will be in error.

A line is said to be operated without phase control when no voltage and power factor regulation, in the form of synchronous condenser capacity, is installed at the receiving end. Accordingly the supply voltage, assuming constant receiver power factor and constant receiver voltage, will vary directly with the load.

When a transmission circuit is operated with phase control, the voltage at both ends of the line can be maintained at a constant and predetermined value if enough condenser capacity is available. It is not in general considered advisable to maintain the same voltage at both ends of the line since in most cases, at normal or 100 percent load, this would require excessive leading condenser capacity. The leading condenser capacity generally should be about 60 percent of normal full load when the load power factor is about 80 percent lagging. Such an arrangement will raise the receiver power factor to about 100 percent and maintain the supply voltage at about 104 percent of the receiver voltage, depending to a certain extent on the size, character, and spacing of the transmission line conductors. Synchronous condensers generally should have a lagging capacity of about 60 percent of their leading capacity.

For a line operated with phase control, constant receiver and constant supply voltage, the receiver power factor will vary with the load. With decreasing load the power factor becomes more and more lagging.

There have been numerous transmission line performance diagrams published, but usually such diagrams have been constructed to indicate performance at full load only. The diagrams herewith presented are constructed to give a picture of what takes place over the entire range from zero to 100 percent load, both without and with phase control. At loads other than indicated the values can be scaled with fair accuracy.

Practical example

In order that the problem may fall within the field of practical application, consideration is given, both analytical and graphical, to the performance of a transmission circuit of the following characteristics:

> 120 miles in length, operating voltage 132 kv, three-phase, 60 cycles; 336,400 cir mils A. C. S. R., stranded 30al/7st, equivalent spacing 15 feet. 100 percent load assumed to be 37,500 kva, 30,000 kw at 80 percent lagging power factor.

The load is assumed to be taken on the high voltage side of the receiving end transformers and thus includes the transformer and condenser losses. This assumption is justifiable since the load of 37,500 kva was assumed for the purpose of calculation, and it would rarely be the same as the actual load. Furthermore, the assumed power factor of 80 percent lagging may only be an approximation of the actual

value. Therefore, it is inadvisable to complicate the problem by pretending to take into account a mere one to two percent transformer losses and a negligible voltage drop through the transformer windings. This type of problem should not be confused with a network study which, of course, must include transformer impedances.

Figure 1 represents a physical conception of what takes place in a transmission circuit. The symbols r and x represent the resistance and inductive reactance of the circuit in ohms. The symbols g and b represent the conductance and susceptance of the circuit in mhos. This is the way they would appear in an artificial circuit shown lumped at four points along the circuit. Actually, these four constants are distributed not exactly uniformly, but approximately so, throughout the entire length of the circuit.

The conductance g for a well-designed line may be taken as zero. However, the susceptance b, for lines of any considerable length, is an all-important property since this is the item which causes most of the trouble in long-line problems. The capacitance, or condenser effect, produces a charging current which, flowing through the resistance and reactance of the circuit, modifies the linear constants (resistance and reactance) and makes necessary the computation of what is known as the auxiliary constants A, B, and C. The auxiliary constants of a circuit are independent of the voltage or current but are functions of physical properties of the line and the frequency.

Unit linear constants

$r=0.278$ ohm resistance.

$x=0.758$ ohm reactance.

$$b=377\left(\frac{0.038829}{\log 2D/d}\right)$$

$2D=2\times15\times12=360$=two times the conductor spacing in inches.

$d=0.741$ inch diameter of conductor.

$2D/d=360/0.741=485.83$, the log of which is 2.6864843.

$b=377\ (0.038829/2.6864843)=5.4488$ micromhos susceptance per mile.

g is taken as zero.

$R=rl=0.278\times120=33.36$ ohms total resistance.

$X=xl=0.758\times120=90.96$ ohms total reactance.

$Z=R+jX=33.36+j90.96$ vector ohms.

$B=bl\times10^{-6}=5.4488\times120\times10^{-6}=0.00065386$ mho total susceptance.

$G=gl=0\times120=0$ mho conductance.

$Y=G+jB=0+j0.00065386$ mho susceptance.

Auxiliary constants

CONSTANT $A=a_1+ja_2$. The auxiliary constants a_1 and a_2 determine the length and position of the sending end voltage vector at zero load. For all practical purposes, constant a_1 may be taken to equal the receiving end voltage minus the reactance volts drop due to the charging current. Constant a_2 represents the resistance volts drop due to the charging current for each volt at the receiving end of the line.

CONSTANT $B=b_1+jb_2$. Constants b_1 and b_2 represent the resistance and reactance in ohms modified by the distribution effect of the circuit. Multiplying these constants by the receiving end current will give the voltage consumed by the resistance and reactance of the circuit. Because of the distribution effect, constants b_1 and b_2 will be somewhat less than the linear constants R and X. The distribution effect is a result of the voltage consumed by the charging current. The impedance triangle will be smaller than it would be in a line with no capacitance.

CONSTANT $C=c_1+jc_2$. Constants c_1 and c_2 represent the conductance and susceptance of the circuit. The value of c_1, except for lines of great electrical length, may safely be considered as negligible. Constant c_2 represents the line charging current for each volt at the receiving end of the line. Multiplying c_2 by the receiving end voltage to neutral gives the total line charging current.

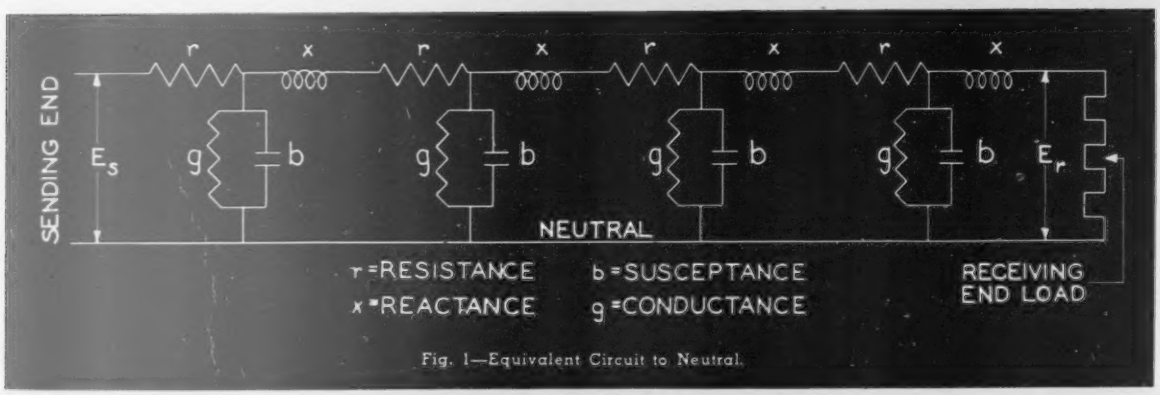


Fig. 1—Equivalent Circuit to Neutral.

The auxiliary constants A, B, and C are derived from the following equations:

$$(1)\quad A=\cosh\sqrt{YZ}=[1+(YZ)/2+(Y^2Z^2)/24+\ldots]$$

$$(2)\quad B=\sqrt{\frac{Z}{Y}}\sinh\sqrt{YZ}=Z[1+(YZ)/6+(Y^2Z^2)/120+\ldots]$$

$$(3)\quad C=\sqrt{\frac{Y}{Z}}\sinh\sqrt{YZ}=Y[1+(YZ)/6+(Y^2Z^2)/120+\ldots]$$

Substituting the numerical values in (1), (2), and (3) and solving:

$a_1+ja_2=0.9703905+j0.010798.$
$A=0.97045/0°38'15''.$

$b_1+jb_2=32.7+j90.18.$
$B=95.93/70°04'07''.$

$c_1+jc_2=-0.00000236+j0.0006474.$
$C=0.0006474/90°12'26''.$

The exact equations of the transmission circuit, with the operations performed vectorially, are as follows:

$$(4)\quad E_{sn}=E_{rn}A+I_rB=E_1+E_2$$

$$(5)\quad I_s=I_rA+E_{rn}C=I_1+I_2$$

Where E_{sn} = sending end voltage to neutral, load condition.

E_1 = sending end voltage to neutral, zero load (constant).

E_2 = impedance drop modified by the distribution effect.

I_s = sending end current.

I_1 = receiving end current modified by the distribution effect.

I_2 = line charging current (constant).

Construction of Figure 2

Vector OR represents the receiving end voltage to neutral, equaling 132,000/1.732 = 76,212 volts. This may be assumed to be 100 percent voltage and used as the reference vector. OB, paralleling OR and coincident with it, is equal to $E_{rn}a_1=76{,}212\times0.9704=$ 73,957 volts. BC is drawn from B at right angles with OR in a leading direction and equal to $E_{rn}ja_2=76{,}212\times j0.0108=j823$ volts.

Then $OC=E_1=73{,}960$ volts, leading vector OR by 0°38′. E_1 is of fixed length and constant slope and determines the length and position of the sending end voltage vector at zero load. With negligible error the length of line BR may be taken to represent the voltage consumed by the charging current flowing through the reactance of the circuit.

For a line of this character, the error will be negligible if it is assumed that the line charging current c_2 flows through one-half the reactance of the circuit. For example, $0.0006474\times90.96/2=.029444$. The quantity a_1 would then equal $1.000000-0.029444=0.970556$. The exact vaue of a_1, calculated rigorously, $=0.9703905$. Also if it is assumed that the line charging current flows through one-half the resistance, $a_2=0.0006474\times33.36/2=0.0107986$. The value of a_2 calculated rigorously to six places is 0.010798.

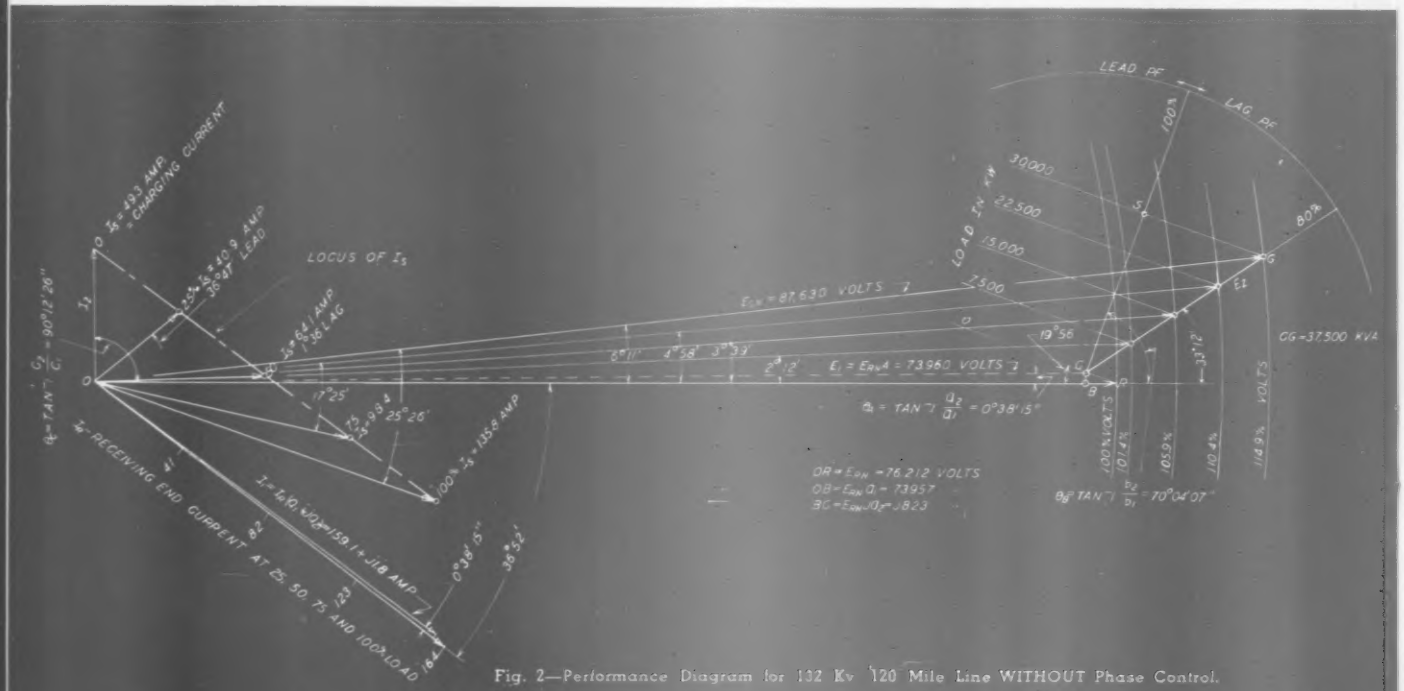

LEAD PF
LAG PF
100%
80%
LOCUS OF I_s
I_s = 193 AMP. = CHARGING CURRENT
E_{sn} = 87,630 VOLTS
$E_1 = E_{rn}A$ = 73,960 VOLTS
$\theta_1 = \tan^{-1}\frac{a_2}{a_1} = 0°38'15''$
$\theta_2 = \tan^{-1}\frac{b_2}{b_1} = 70°04'07''$
OR = E_{rn} = 76,212 VOLTS
OB = $E_{rn}a_1$ = 73957
BC = $E_{rn}ja_2$ = j823
CG = 37,500 KVA
100% VOLTS
101.4%
105.9%
110.4%
114.9% VOLTS
I_r = RECEIVING END CURRENT AT 25, 50, 75 AND 100% LOAD
$I_r = I_1 - I_2 = 159.1 + j118$ AMP.

Fig. 2—Performance Diagram for 132 Kv 120 Mile Line WITHOUT Phase Control.

If the line were without capacitance, the impedance triangle would have as origin the point R, the end of the receiver voltage vector. Obviously since the circuit under discussion contains considerable capacitance, the impedance triangle, of which line CG forms the hypotenuse, must be raised and rotated to the left to point C, which is the terminus of the sending end voltage vector.

Next the 100 percent power factor line is laid off from C, making an angle with OR of $\Theta_B = \text{Tan}^{-1}b_2/b_1 = 70°04'$. The load per phase equals 37,500/3=12,500 kva, from which I_r, at 100 percent load and 80 percent lagging power factor, equals 12,500/76.212=164 amp. 164(0.8−j0.6)=131.21−j98.4 vector amperes. The impedance drop $I_rB=E_2=(131.21-j98.4)\ (32.7+j90.18) = 13{,}164+j8{,}615=15{,}732/33°12'$ volts. G is located on this line at a distance from C equal to 15,732 volts to the same scale as OR. From equation (4), $E_{sn}=E_1+E_2=73{,}957+j823+13{,}164+j8{,}615=87{,}121+j9{,}438=87{,}630/6°11'$ volts.

Line CG represents the load kva, but of course to a different scale. Line CG is displaced from the 100 percent power factor line by 70°04′−33°12′=36°52′. (80 percent power factor.)

A line is drawn to the left from G bisecting the 100 percent power factor line at S. Line CS corresponds to 30,000 kw at 100 percent power factor. Line CS is divided, as shown, into four equal parts to represent 25, 50, 75, and 100 percent loads. Lines through these points and perpendicular to line CS join line CG at points which correspond to the termini of the sending end voltage vector E_{sn} at the given load. E_2 at constant power factor will be of constant slope but of variable length, depending on the load.

At zero load the ratio of E_{sn} to E_{rn} is constant, that is, the ratio of E_{sn} to E_{rn} is expressed by the auxiliary constant A. The ratio of E_{rn} to E_{sn} is equal to 1/A. Should the load be thrown off and E_{sn} remain constant at 87,630 volts, E_{rn} would rise to 87,630/.9704=90,303 volts. This is equal to 3.05 percent of normal full load supply voltage and 18.5 percent of normal full load receiver voltage.

Construction of the current diagram

Vector I_r is laid off from O to any convenient scale equal to 12,500/76.212 = 164 amp displaced from OR in a lagging direction 36°52′. $I_1=I_r(a_1+ja_2)=(131.21-j98.4)\ (0.9704+j0.0108)=128.38-j94.07=159.15/-36°52'$ amp, referred to vector OR, or $164(0.9704+j0.0108)=159.1+j1.8=159.15/0°38'$ amp referred to vector I_r. I_1 is of variable length and constant slope, depending on the load.

Vector I_2 is laid off in a leading direction to represent the line charging current, making an angle with OR of $\tan^{-1}c_2/c_1 = 0.0006474/-0.00000236 = 90°12'26''$. $E_{rn}(c_1+jc_2) = 76.212(-0.00000236+j0.0006474)=-0.18+j49.34=49.34/90°12'$ amp. This represents the total line charging current, usually designated I_c. I_2 is of fixed length and constant slope. From equation (5), $I_s=I_1+I_2=128.38-j94.07-0.18+j49.34=128.2-j44.73=135.78/-19°14'$. I_s lags E_{sn} by −19°14′ −6°11′=−25°25′. The sending end power factor $(pf)_s$ is therefore 90.32 percent lagging.

The line performance data at the given loads are given in Tables I and II.

TABLE I

Percent Load	E_2 Volts	E_{sn} Volts	I_1 Amp	I_s Amp
100	15,732	87,630/6°11′	159.15	135.78/−19°14′
75	11,709	84,145/4°58′	119.37	98.40/−12°27′
50	10,742	80,701/3°39′	79.58	64.05/2°03′
25	3,943	77,305/2°12′	39.79	41.05/38°59′
0	0	73,960/0°38′	0.00	49.34/90°12′

Notes: E_1 constant at 73,960 volts.
I_2 constant at 49.34 amperes.
$(pf)_r$ constant at 80 percent lagging.

TABLE II

Percent Load	$(Kw)_s$	$(Kw)_r$	Loss Kw	$(Kva)_s$	$(Pf)_s$ %
100	32,241	30,000	2,241	35,697	−90.32
75	23,706	22,500	1,206	24,842	−95.42
50	15,501	15,000	501	15,507	−99.96
25	7,627	7,500	126	9,520	80.10
0	82	0	82	10,948	0.75

Note: The minus sign indicates lagging power factor.

Line performance with phase control

If the transmission circuit extends from a system the voltage of which cannot be varied except within quite narrow limits, it will be necessary to provide enough condenser capacity to maintain the voltage practically constant and within certain prescribed limits. On the other hand, should quite a large voltage variation be permissible, logically, less leading condenser capacity will be necessary.

In case the installation may be required to carry 125 percent load, for example, then it would be well to provide sufficient condenser capacity to raise the power factor at normal load to about 100 percent. This is necessary to supply a reasonable amount of excess load carrying capacity without producing excessive voltage variation. It is not advocated, how-

ever, that the power factor should be held at unity at all times. When the value of E_{sn} or ratio of E_{sn} to E_{rn} is once established, the leading condenser capacity will be fixed.

Construction of Figure 3

OR, OB, and BC are laid off in the same manner and to the same scale as described for Fig. 2. Also the 100 percent power factor line is drawn from C, making the same angle 70°04′ with vector OR. From this line CH is drawn, lagging 36°52′. In this case the leading condenser capacity is assumed to be 60 percent of the normal kva load or $0.6 \times 37{,}500 = 22{,}500$ kva. This to the same scale as CH is represented by the line GH. The effect of the condenser is to raise the power factor from 80 percent lagging to unity.

At unity power factor $I_r = 10{,}000/76.212 = 131.21$ amp, from which $E_2 = 131.21(32.7 + j90.18) = 4{,}291 + j11{,}832 = 12{,}587/70°04'$ volts. $E_{sn} = E_1 + E_2 = 73{,}957 + j823 + 4{,}291 + j11{,}832 = 78{,}248 + j12{,}655 = 79{,}264/9°11'$ volts. E_{sn} is then constant at 79,264/76,212 = 104 percent of E_{rn}. The locus of E_{sn} will fall on the arc of a circle, represented by arc DXG.

Line GH represents the maximum leading condenser capacity required to maintain E_{sn} at 104 percent of E_{rn} at normal full load. With constant supply and constant receiver voltage over the entire range from 100 percent to zero load, the condenser capacity will vary from a miximum leading at 100 percent load to zero capacity at about 11,500 kw, at which load it will just be floating on the line. As the load drops further, the condenser capacity required will become more and more lagging, reaching a maximum at zero load where it will be 60 percent of the maximum leading capacity.

Now the 0, 25, 50, and 75 percent loads are measured on line CG. Through these, at right angles with line CG, lines are drawn representing 0, 7,500, 15,000, and 22,500 kw loads, intersecting the voltage arc at D, L, M, and N. Extreme care should be exercised in the construction of this part of the diagram, as graphical construction is used for determining the power factor and kva values at intermediate loads. Points L, M, and N must be located very accurately on the voltage arc, otherwise the angle of lag cannot be read correctly, as a result of which the computed value of I_r will be in error. Then the I_rB drop, represented by E_2 at the given load, will be in error, and the sum of E_1 and E_2 will not check with the previously determined value of E_{sn}.

Sending end current diagram

The construction of a current diagram for lines operating with phase control is somewhat more involved than for lines operating without phase control. For this reason it is advisable to construct a separate current diagram to include all vectors for the complete solution. Accordingly, before attempting to complete the current diagram of Fig. 3, reference should be made to Fig. 4. This diagram includes certain vectors which are not essential to a performance diagram but which are necessary for the complete solution.

To construct the complete current diagram of Fig. 4, the line indicated by E_{rn} is drawn. Then line OP is

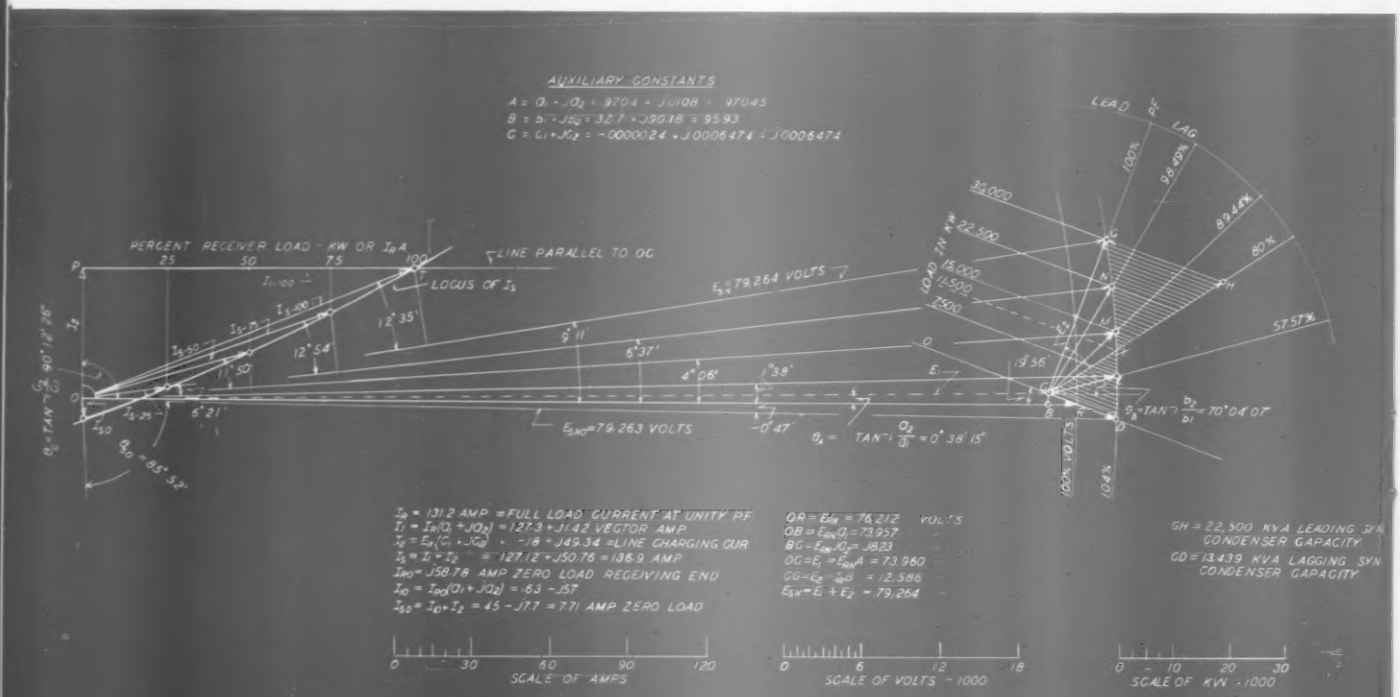

AUXILIARY CONSTANTS
A = D1 + JD2 = .9704 + J.0108 = .97045
B = b1 + Jb2 = 32.7 + J90.18 = 95.93
C = C1 + JC2 = -.0000024 + J.0006474 = J.0006474
PERCENT RECEIVER LOAD - KW OR IRA
LINE PARALLEL TO OC
LOCUS OF Is
Es=79,264 VOLTS
ESNO=79,263 VOLTS
LEAD
PF
LAG
LOAD IN KW
30,000
22,500
15,000
11,500
7500
100%
98.48%
89.44%
80%
57.57%
100% VOLTS
104%
IR=100 = 131.2 AMP =FULL LOAD CURRENT AT UNITY PF
I1 = IR(D1 + JD2) = 127.3 + J31.42 VECTOR AMP
I2 = ER(C1 + JC2) = -.18 + J49.34 =LINE CHARGING CUR
IR = I1 + I2 = 127.12 + J50.76 = 136.9 AMP
IR0 = J58.78 AMP ZERO LOAD RECEIVING END
I0 = IR0(D1 + JD2) = .63 - J57
IS0 = I0 + I2 = 45 - J7.7 = 7.71 AMP ZERO LOAD
OR = ER = 76,212 VOLTS
OB = ERD1 = 73,957
BG = ERD2 = J823
OC = E1 = ERA = 73,960
CG = E2 = eB = 12,586
ESN = E + E2 = 79,264
GH = 22,500 KVA LEADING SYN CONDENSER CAPACITY
CD = 13,439 KVA LAGGING SYN CONDENSER CAPACITY
SCALE OF AMPS
SCALE OF VOLTS - 1000
SCALE OF KW - 1000

Fig. 3—Performance Diagram for 132 Kv 120 Mile Line WITH Phase Control.

drawn to represent the line charging current, $I_2 = -0.18 + j49.34$ vector amp, as referred to vector E_{rn}. With P as origin, line PS is drawn parallel with E_{rn}. Then $I_1 = I_r(a_1 + ja_2) = 131.21(0.9704 + j0.0108) = 127.33 + j1.42 = 127.33/0°38'$ amp as referred to vector PS. This is indicated by line PT. Then $I_{s-100} = I_1 + I_2 = 127.33 + j1.42 - 0.18 + j49.34 = 127.15 + j50.76 = 136.9/21°46'$ amp, indicated by vector OT.

In this same manner the values of I_{s-75}, I_{s-50}, I_{s-25}, and I_{s-0} are computed at the given loads and these vectors drawn on the diagram. The value and phase position of each current vector is given in Table III. The receiver power factor, receiver current, impedance drop and sending end voltage are compiled in Table IV.

It is not essential to locate the center of the current circle; however, the coordinates of the center of the circle may be determined as follows:

$$-1 + jm = \frac{a_1 - ja_2}{b_1 - jb_2}$$

$$= \frac{0.9704 - j0.0108}{32.7 - j90.18}$$

$$= -0.003554 + j0.009472$$

The coordinates of the center of the circle are

$$-1E_{rn} = -0.003554 \times 76{,}212 = -270.88 \text{ amp}$$

$$mE_{rn} = 0.009474 \times 76{,}212 = 721.88 \text{ amp}$$

$$\text{Radius} = E_{sn}/B = 79{,}264/95.93 = 826.26 \text{ amp}$$

OV is drawn making an angle of 90 degrees with line PS. From OV a line is drawn, as shown, at an angle of 0°38'+19°56'=20°34'. This will be the line of centers, regardless of the scale used. It should be kept in mind, however, that any change in the length of the radius, along this line of centers, will affect all other vectors, such as I_1, I_2, etc., in like proportion.

By referring again to Fig. 3, it will be seen that all essential values necessary for determination of the line performance have been represented. I_{s-100}, I_{s-75}, I_{s-50}, I_{s-25}, and I_{s-0} are drawn with the same angular displacement from vector OR on Fig. 3 as from vector E_{rn} on Fig. 4. The radius of the current arc on Fig. 3 is 2.085 times the radius of the voltage arc.

If the sending end current vectors were drawn to the same scale as vectors CG, CN, etc., the current circle arc would be exactly the same as the voltage arc.

TABLE III

Percent Load	I_1 Amp	I_2 Amp	I_s Amp
100	127.33/0°38'	49.34/90°12'	136.90/21°46'
75	96.92/−9°12'	49.34/90°12'	101.30/19°31'
50	71.18/−25°57'	49.34/90°12'	66.39/15°56'
25	55.29/−54°13'	49.34/90°12'	32.47/7°59'
0	57.05/−89°39'	49.34/90°12'	7.71/−86°39'

TABLE IV

Percent Load	$(Pf)_r$ %	I_r Amp	I_rB Volts $(E)_2$	E_{sn} Volts (E_1+E_2)	$(Pf)_s$ %
100	100.00	131.21/0°00'	12,587/70°04'	79,264/9°11'	97.60
75	−98.49	99.91/−9°50'	9,583/60°14'	79,264/6°37'	97.48
50	−89.44	73.35/−26°35'	7,037/43°29'	79,264/4°06'	98.53
25	−57.57	56.98/−54°51'	5,467/15°13'	79,264/1°38'	99.39
0	−0.00	58.78/−90°17'	5,639/−20°13'	79,264/−0°47'	−5.47

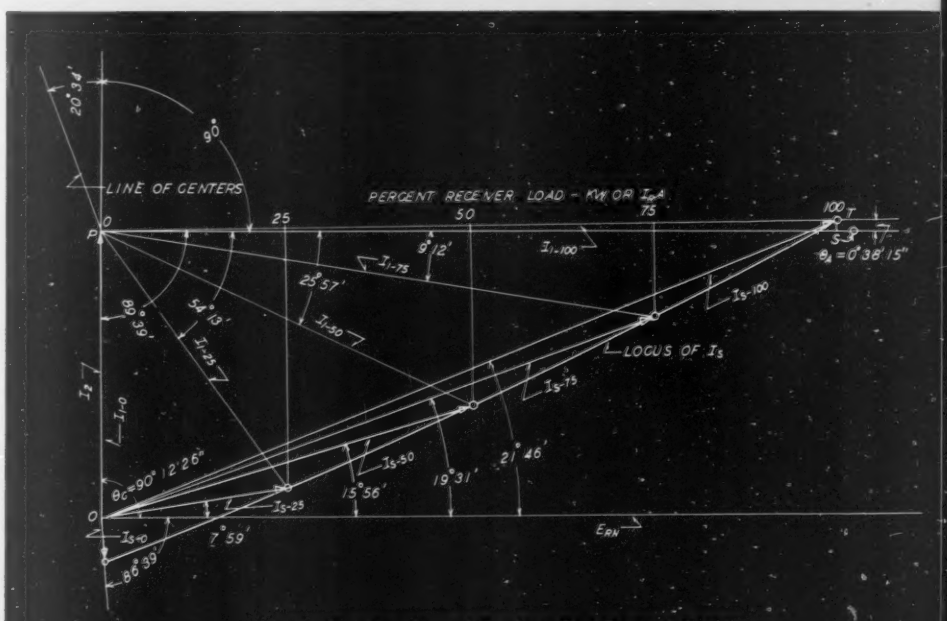
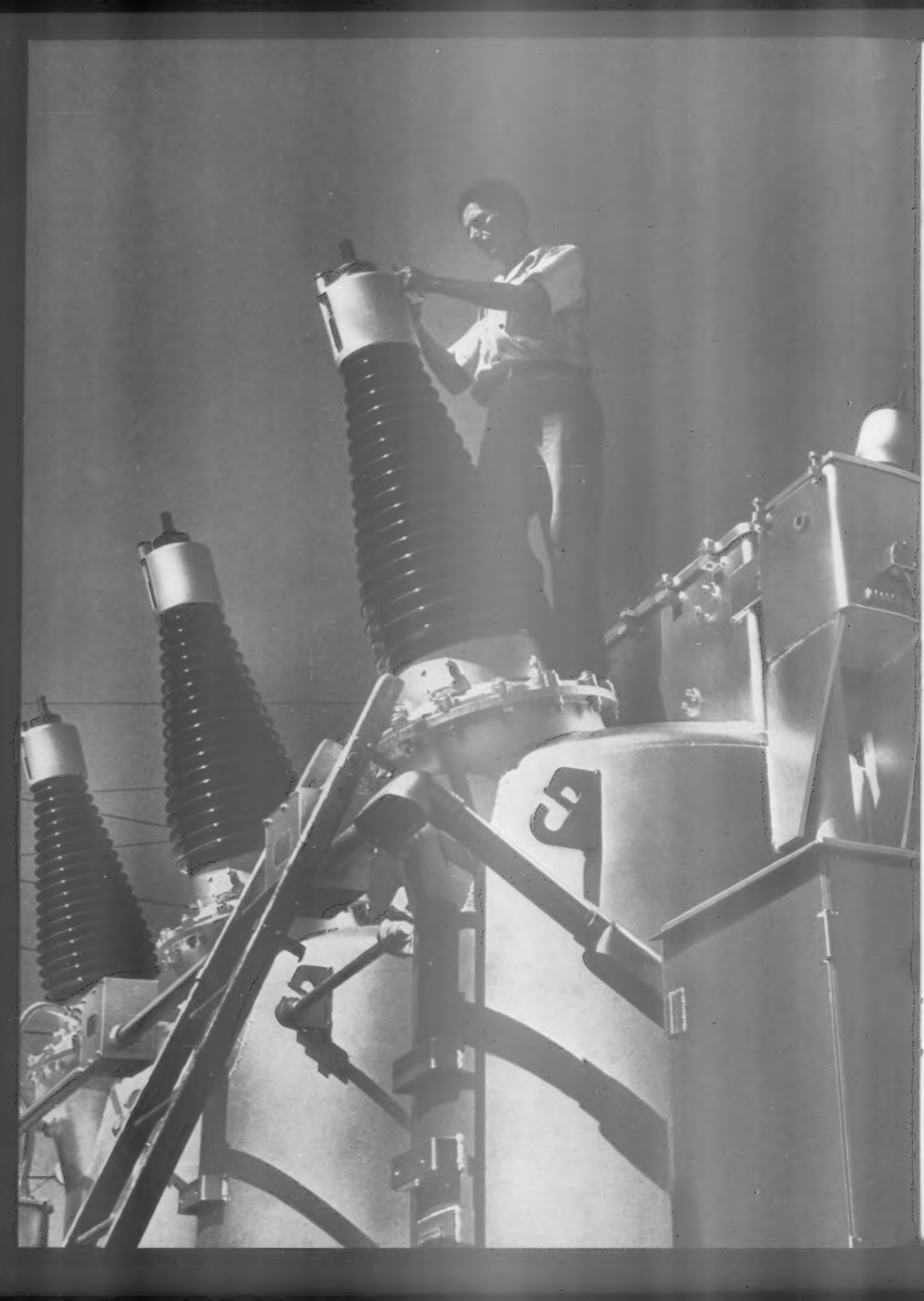


Fig. 4—Construction of Sending End Current Vectors.



Most efficient receiver power factor

It is a general assumption that maximum transmission efficiency will prevail when the receiver power factor is 100 percent. This is not true, however, for lines of any considerable length. Maximum transmission efficiency is obtained when the receiver power factor is slightly lagging. In this particular case, minimum losses occur with a receiver power factor of 98.315 percent lagging.

With a receiver power factor of 98.315 percent lagging, E_{sn} equals 81,316 volts. The receiver load is $P_r - jQ_r = 10{,}000 - j1{,}860 = 10{,}171$ kva per phase. The load at the sending end is $P_s + jQ_s = 10{,}571 + j677 = 10{,}594$ kva. The loss is 571 kw. The leading condenser capacity required is 5,534 kva per phase.

With a receiver power factor of 100 percent, E_{sn} would be 79,264 volts. The receiver load would be $P_r + jQ_r = 10{,}000 + j0 = 10{,}000$ kva. The load at the sending end would be $P_s + jQ_s = 10{,}590 + j2{,}267 = 10{,}851$ kva. The loss would be 590 kw. The condenser capacity required would be equal to 7,500 kva per phase.

This is more important than just a casual glance would indicate. For example, the line losses at unity power factor are 3.33 percent more than at 98.315 percent lagging, and unity power factor requires nearly 2,000 kva per phase, or 35 percent more condenser capacity.

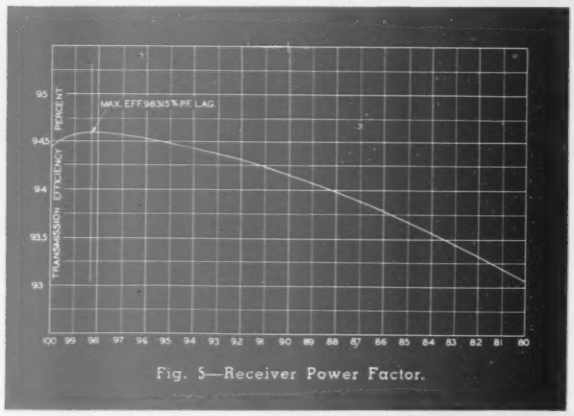


Fig. 5—Receiver Power Factor.

Figure 5 indicates transmission efficiency plotted against receiver power factor. It is interesting to note that at 93.8 percent power factor the efficiency is the same as at 100 percent power factor.

AT LEFT: Before this high capacity outdoor oil circuit breaker is put into service, its bushings receive a final check-up.

ON FOLLOWING PAGES: Winding a high voltage coil of a 40,000 kva, 230,000 volt, single-phase, water-cooled transformer.

New Motor-Pump Unit

Motor end bell and centrifugal pump housing are cast in one piece to get an exceptionally compact pumping unit. Widely spaced feet underneath the pump make the unit very rigid, and the motor is built of splash-proof construction.

Another feature of this unit is that the stator core and coils of the motor is removable as a unit. This feature has been incorporated to permit quick changing of motor characteristics when it is desired to use the unit under different operating conditions.

Motor-pump combinations of this construction are available for ratings of ¾ hp at 1800 rpm up to 25 hp at 3600 rpm.

Dry Type Air-Cooled Regulator

Air-cooled and air-insulated windings and a special tap-changing mechanism eliminate all oil from a new single-phase feeder voltage regulator introduced recently. This machine is designed for operation in locations where oil-filled apparatus would be considered a fire hazard.

The units are slightly larger than oil-filled voltage regulators of similar capacities, but the air-cooled units do not require fireproof vaults. Hence, there is actually a net saving in space because they can be mounted right next to each other.

Capacities from 36 to 96 kva, single phase, 2400 volts, are available, and larger units are being developed. The regulator gives a voltage range of plus or minus 10 percent in ⅝ percent steps.

No fans are required to maintain air circulation in the unit. The bearings are permanently lubricated so that the regulator requires little attention.

For further, more detailed information regarding these new products, write the Editors of ELECTRICAL REVIEW.

THE WATER CURE

F. J. Arnaud

TRANSFORMER DIVISION • ALLIS-CHALMERS MANUFACTURING COMPANY

In sanitariums, water is used to avoid physical breakdown. But in transformers water may cause a breakdown . . . and its removal from windings and insulation has developed into an exact science as well as a small scale air-conditioning problem.

● None of the insulating materials entering into the manufacture of an electrical machine are completely dry when they reach the manufacturer. Moreover, during the processes of manufacture, the insulating materials which are hygroscopic have an opportunity to absorb still more moisture from the surrounding atmosphere. Therefore, it is essential that these materials be dried after fabrication before the machines in which they have been used are placed in service.

To dry insulating material it is necessary to supply enough heat to vaporize the absorbed moisture and yet maintain the temperature low enough to prevent deterioration of the insulating materials. As the moisture vaporizes, it must be removed from the proximity of the insulating material so that it will not retard the evaporation of the remaining moisture. The usual equipment employed by electrical machinery manufacturers to dry fabricated insulating material is a vacuum dehydrating tank having insulated walls strong enough to withstand atmospheric pressure on the outside with the inside evacuated to a practically perfect vacuum.

The use of air

Steam coils or other heaters located within the tank, or a tank jacket in which hot air is circulated, are used to supply the heat to vaporize the moisture which it is desired to remove from the apparatus placed in the tank. The tank cover is locked in place and the air in the tank exhausted by a vacuum pump. The pressure is reduced in order that the vapor pressure of the moisture, which is determined by its temperature, shall be a greater percentage of the total pressure.

To increase the rate of evaporation, dried, heated air may be introduced into the tank to replace that which has become saturated with water vapor. The substitution of dry air also serves to improve circulation within the vacuum tank and to reduce the temperature differential between its different parts. To improve further the circulation of air throughout the vacuum tank, at regular intervals the pressure within the tank is increased to atmospheric pressure by bleeding in air.

Regulation of heat

Thermocouples located in various places in the tank and in the apparatus being dried are used to determine the temperature at which the process of dehydration is progressing so that it may be kept within safe limits. Usually a printed record of these temperatures and also of the pressure within the tank is made by continuous recording meters. Certain windings of the apparatus being dried, such as a transformer, are connected to terminals located in the vacuum tank wall. The connections brought through the tank wall by these terminals are used to measure the insulation resistance, capacitance, and power factor, all of which aid in the determination of the dryness of the insulating material.

To provide closer control, obtain a more complete record, and reduce the supervision required, equipment has been developed which automatically controls the vacuum tank during the process of drying and records the cycle of operations. Essentially, this apparatus consists of three component parts.

Control apparatus

The vacuum and temperature control of the tank consists of a time switch which, with its associated equipment (Fig. 1), maintains a definite cycle of operation. For the major portion of each cycle, the vacuum pump is in operation, removing water-saturated air from the tank, which is maintained at a constant temperature

by means of steam coils or other heaters. During this part of the cycle, clean, dry, heated air is admitted to the tank by a reducing valve set to maintain the desired degree of vacuum. During the remaining portion of the cycle, a time switch connects the interior of the tank directly to atmosphere, thereby breaking the vacuum completely. During all this time, the pressure within the vacuum tank and the temperatures of the various portions of the tank and parts of the transformer or other apparatus being dried have been continuously recorded by means of recording vacuum gauge, thermometers, and pyrometer (Figs. 2 and 3) with thermocouples distributed at various places in the tank and throughout the transformer. Figs. 4 and 5 are typical records.

The second part of the control equipment (Fig. 6) is designed to give a continuous record of the insulation resistance of the transformer being dried. It consists of a d-c source that periodically supplies power for four minutes to an automatic recording insulation resistance meter which records once every minute on a moving tape. Thus three or four readings spaced one minute apart are obtained periodically. The purpose of obtaining three readings spaced at one-minute intervals is to eliminate the effect of the charging current of the capacitance. During each four-minute operating period the insulation resistance meter is connected by means of a motor-driven tap changing switch to either a different winding of the machine being dried or to a different machine if more than one machine is being dried at the same time.

The third portion of the automatic equipment is designed to protect the vacuum pump and associated machinery against possible damage. It consists of under-voltage and over-load protection on motor circuits and thermocouples on all bearings and cooling surfaces of the compressor, compressor motors and circulating fans. If any bearing should overheat, or if the circulating water that cools the vacuum pump should fail, the driving motor shuts down, and an alarm is sounded which indicates by signals which element of the many protective devices has tripped.

Electrical circuits

A simplified wiring diagram of the automatic vacuum tank control equipment is shown in Fig. 7. Most of the automatic equipment of the control illustrated operates from an a-c source which has one side grounded. The protective thermostats, of which only three are shown in each circuit, are mounted on the bearings and other portions of the circulating fan and its motor and on the motor bearing and cylinders of

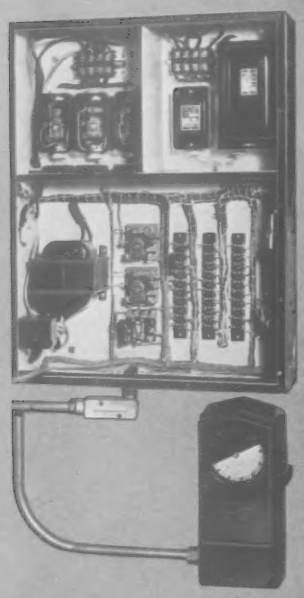


Fig. 1 — Automatic cycling equipment for vacuum tank control.

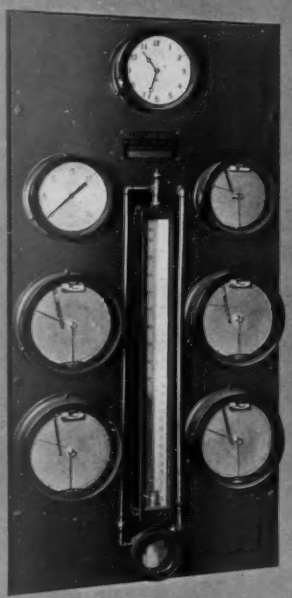


Fig. 2 — Recording thermometers and pressure gauges.

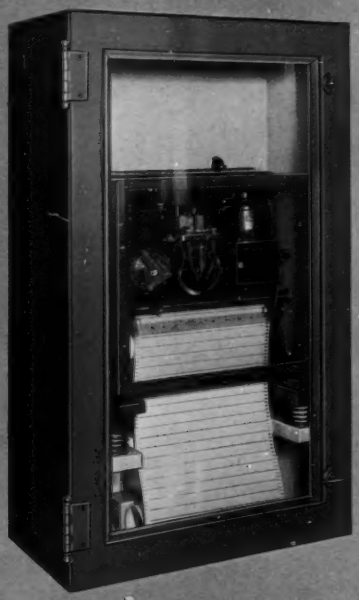


Fig. 3 — Recording pyrometer for the vacuum tank.

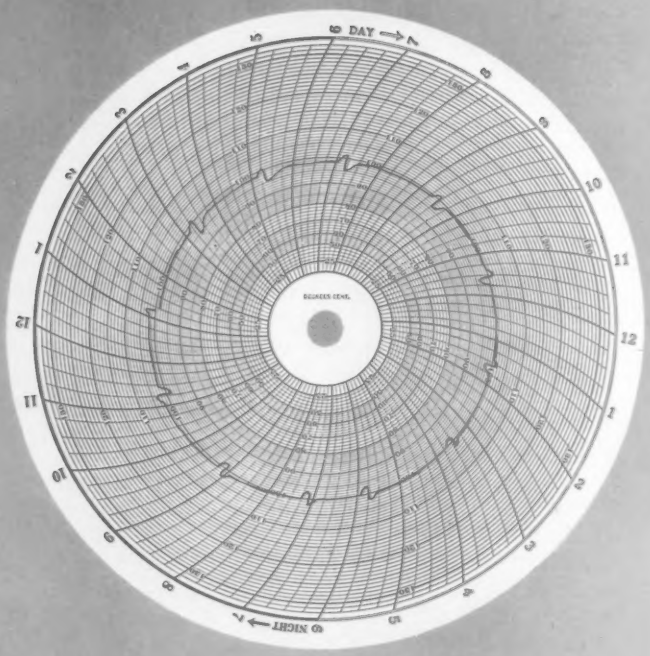


Fig. 4—Temperature Record of Interior of Vacuum Tank.

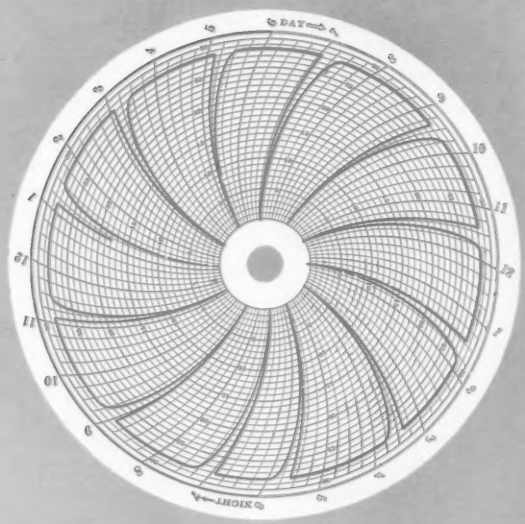


Fig. 5—Vacuum Chart of Internal Pressure.

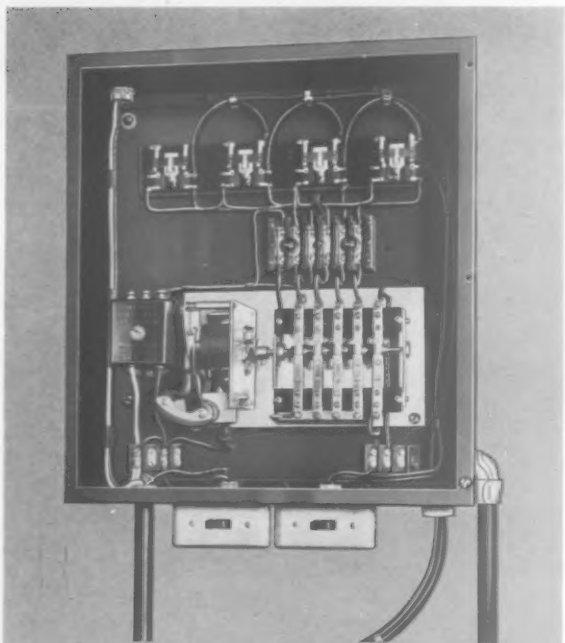


Fig. 6 — Control equipment for automatic insulation resistance recording.

the vacuum pump. As long as the temperature of each of these thermostats is below that for which the thermostat has been set, the current for the relay coils flows through the associated set of thermostats in series, and the relay is actuated. When any of these thermostats exceeds the permissible temperature limit, it opens the circuit to the relay coil, and the relay is deenergized. The back contacts on the relay light an appropriate indicating lamp.

Since the thermostats mounted on the vacuum pump are subjected to vibration, they are so connected that the thermostat contacts do not carry the current of the relay coil after the relay has closed. This current is carried by a set of contacts on the relay itself. When any one of these thermostats exceeds the allowable temperature limit, it short circuits and deenergizes the relay, causing it to drop out.

If none of the protective thermostats is overheated, the fan circulates air through the heaters and around the outside of the tank. Other temperature detector elements mounted in the inlet and outlet of the tank jacket, and therefore responsive to the tank wall temperature, control motors which open and close the steam admission valves to the heater coils. These valve operators also actuate potentiometers which supply a varying voltage to a solenoid whose pull acts

on the temperature detector in the same direction as an increase in temperature.

Valve operation

Thus the farther the valves are open, the more steam admitted, and, consequently, the greater the pull on the thermostat and the lower the temperature at which the thermostat will balance and stop the temperature rise. This proportioning feedback prevents hunting on the part of the valve operators. By means of limit switches built into the two-valve operators which control the two portions of the heating coils, the valves are made to open and close in sequence. The first opens completely before the second starts to open, and the second closes completely before the first starts to close. This division of the heating surface into two parts and the interlocked control of the parts permit a closer control over the heat added to the vacuum tank.

The pressure within the vacuum tank is controlled by a contact-making vacuum gauge which electrically controls an air inlet valve. This air inlet is a valve operator similar to those admitting steam to the heating coils. As the vacuum within the tank becomes greater, the contact-making vacuum gauge makes a contact which opens this air inlet valve. As soon as sufficient dried, heated air has been admitted to raise the pressure to the predetermined level, the contact-making vacuum gauge reverses its contacts and closes the valve. This air inlet valve is made to break the vacuum periodically by means of a synchronous motor, which at definite intervals tilts a mercury switch. This tilting mercury switch, through a relay, disconnects and short circuits the contact-making pressure gauge in such a way that the air inlet valve opens.

By means of the automatic operation the vacuum tank is maintained at uniform temperature and pressure. The air within the tank is constantly changed by the vacuum pump, and periodically the tank is swept clean of the saturated air by the vacuum breaking valve. This changing of the air reduces the temperature differentials and the humidity within the tank, thereby increasing the rate of moisture removal. All these elements speed the drying process and insure a more uniformly dry product. In addition to increasing the efficiency, the automatic features of the vacuum tank control reduce the attendance required.

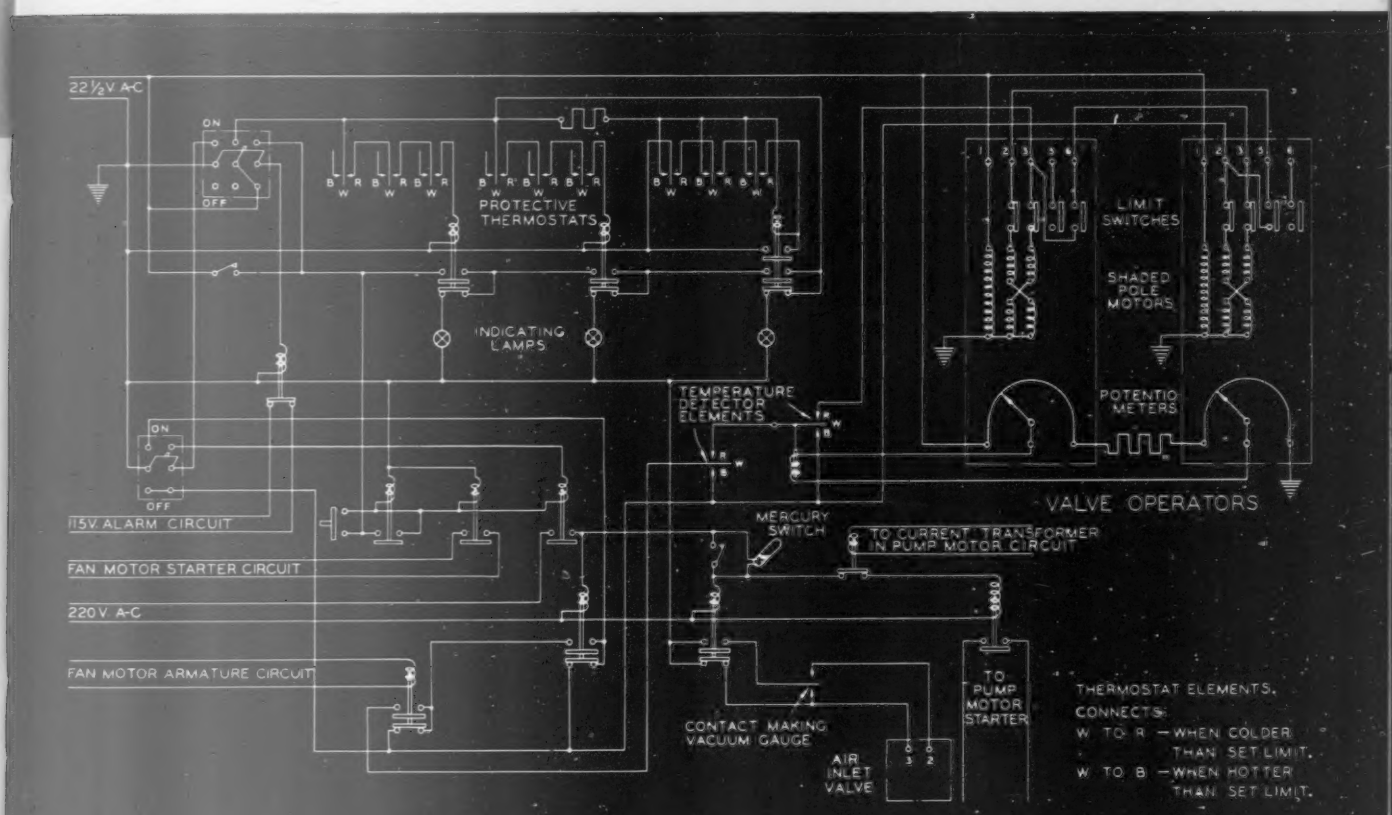


Fig. 7—Simplified Wiring Diagram for Automatic Vacuum Tank Control.

ENGINEERING FUNDAMENTALS

Short-time heating of transformers

● During short circuits on transformers the current in the windings is commonly equal to several times normal current. Such currents can be safely carried for only very short times during which time practically all the heat generated is absorbed by the copper of the windings. Only a negligible percentage of the heat is dissipated by radiation or conduction to the surrounding oil or other cooling mediums. As the copper absorbs heat, its temperature rises.

The standards of the A. I. E. E. are well established not only for the allowable temperatures but also for the starting temperatures to be assumed and for the formulas to be used in calculating the temperature reached.

Both an exact and an approximate formula are given in the standards. The approximate formula has been rewritten in a more convenient form by making a change in the grouping of the terms. The results obtained by the simplified formula are identical with the results obtained by the approximate A. I. E. E. formula.

Curves (Figs. 1 and 2) have been plotted for the most frequent application of these formulas which are: (1) to short circuits on transformers delivering power; and (2) to short circuits on grounding transformers.

The formulas according to A. I. E. E. Standards No. 13 are:

Exact formula

$$T=309.5\sqrt{\left[\left(\frac{T_o+234.5}{309.5}\right)^2+E\right]\log^{-1}At}-E-234.5$$

$$E=\frac{\left(\frac{T+234.5}{309.5}\right)^2-\left(\frac{T_o+234.5}{309.5}\right)^2\log^{-1}At}{\log^{-1}At-1}$$

("log" represents $\log_{10}$)

The curves according to this exact formula are shown in FULL lines in the figures.

Approximate formula rewritten for simplification

$$T=2\,ft\left[(1+ft)(T_o+234.5)+\frac{309.2E}{1+ft}\right]+T_o$$

$$E=\frac{1+ft}{309.2}\left[\frac{T-T_o}{2\,ft}-(1+ft)(T_o+234.5)\right]$$

The curves according to this approximate formula are shown by dotted lines in the figures.

T = Final temperature in degrees C

T_o = Initial temperature in degrees C

E = Ratio of eddy current loss to the I^2R loss (at 75 C).

$A=4\times10^{-11}\times(\text{amp per sq in. of conductor})^2=$

$$=\frac{65}{(\text{Cir mils per amp of conductor})^2}$$

$=1.56\times10^{-5}\times(I^2R$ per lb at 75 C)

t = time in seconds

$f=.576A=2.3\times10^{-11}\times(\text{Amp per sq in. of conductor})^2=\frac{37.5}{(\text{Cir mils per amp of conductor})^2}$

$=0.9\times10^{-5}\times(I^2R$ watts per lb at 75 C)

Curves "A," "B," and "C," "A_1," "B_1," and "C_1" are the curves of allowable current density for transformers delivering power and are based on the following values according to the A. I. E. E. standards:

$T_o=105$ C

$T=250$ C

Curve "A" and "A_1" is the short circuit current density under short circuit conditions for one second.

Curve "B" and "B_1" is the curve of normal density for a transformer which is to withstand 40 times normal current for two seconds.

Curve "C" and "C_1" is the curve of normal density for a transformer which is to withstand 25 times normal current for two seconds.

Curve "D" and "D_1" is the operating current density curve for grounding transformers and is based on the following values according to the A. I. E. E. standards.

$T_o=75$ C

$T=160$ C

$t=60$ seconds

For all curves the value of circular mils per ampere for other times is directly proportional to the square root of the time. For all curves the value of amperes per square inch for other times is inversely proportional to the square root of the time. Curves "A,"

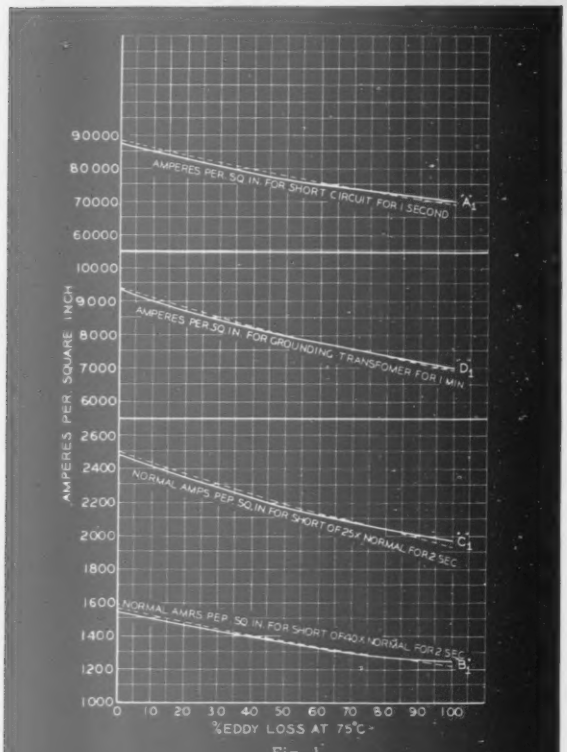

AMPERES PER SQUARE INCH
AMPERES PER SQ IN. FOR SHORT CIRCUIT FOR 1 SECOND
AMPERES PER SQ IN. FOR GROUNDING TRANSFORMER FOR 1 MIN.
NORMAL AMPS PER SQ IN FOR SHORT OF 25X NORMAL FOR 2 SEC.
NORMAL AMPS PER SQ IN FOR SHORT OF 40X NORMAL FOR 2 SEC.
%EDDY LOSS AT 75°C

Fig. 1

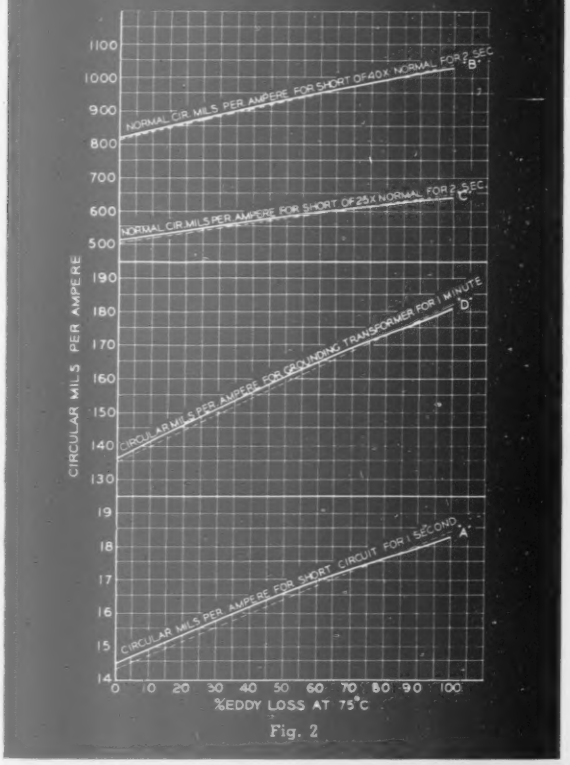

CIRCULAR MILS PER AMPERE
NORMAL CIR. MILS PER AMPERE FOR SHORT OF 40X NORMAL FOR 2 SEC.
NORMAL CIR. MILS PER AMPERE FOR SHORT OF 25X NORMAL FOR 2 SEC.
CIRCULAR MILS PER AMPERE FOR GROUNDING TRANSFORMER FOR 1 MINUTE
CIRCULAR MILS PER AMPERE FOR SHORT CIRCUIT FOR 1 SECOND
%EDDY LOSS AT 75°C

Fig. 2

"A_1," "D," and "D_1" represent actual current density under short circuit conditions. To find the corresponding circular mils per ampere under normal conditions, the value from Curve "A" is multiplied by the number of times normal current in the short. To find the corresponding amperes per square inch under normal conditions, the value from Curve "A_1" is divided by the number of times full load current in the short.

Example

If the eddy current loss is ten percent at 75 C, what is the required normal current density when the short circuit current is 20 times normal for five seconds? The circular mils per ampere for one second from Curve "A" corresponding to ten percent eddy current loss is 14.9. The circular mils per ampere for five seconds $=14.9\times\sqrt{5}=33.3$ on short circuit. The normal circular mils per ampere $=20\times33.3=666$. The same result can be obtained from Curve "B." The value corresponding to ten percent on Curve "B" is 845 circular mils per ampere. The required circular mils per ampere is proportional to the square root of the time and also to the number of times full load current, or $=845\times\sqrt{\frac{5}{2}}\times\frac{20}{40}=666$, which is the same value obtained before.

For amperes per square inch the procedure is similar except that the value of amperes per square inch is inversely proportional to the time and to the number of times full load current.

For calculation of the minimum normal circular mils per ampere for a transformer with impedance of Z percent required to withstand short circuit for a time of t seconds, the following equation is used:

$$\text{Normal circular mils per ampere} = \frac{100\sqrt{t}\ (\text{circular mils per amp from Curve "A"})}{\%\,Z}$$

$=$(circular mils per ampere from Curve "A")$\times$ (Ratio of short circuit current to full load current) $\times\sqrt{t}$

$$\text{Normal amperes per sq in.} = \frac{(\text{Amp per sq in. from Curve "A}_1\text{"})\ (\%\,Z)}{100\sqrt{t}} = \frac{(\text{Amp per sq in. from Curve "A}_1\text{"})}{(\text{Ratio of short circuit current to full load current})\sqrt{t}}$$

The curves shown in Figs. 1 and 2 are applicable to the standard A. I. E. E. temperature conditions. Special cases where the temperatures are different from the standards can be solved by using either of the formulas. The approximate formula is the one in most general use because it is simpler than the exact formula. The difference in the results obtained is slight, as can be determined by a comparison on the solid and dotted line curves of the figures.

By using the curves and the rewritten formulas the information in the A. I. E. E. standards is quickly and conveniently available for all transformers.

W. C. SEALEY.

ROTATING JITTERBUGS

W. F. King

ELECTRICAL DEPARTMENT • ALLIS-CHALMERS MANUFACTURING COMPANY

Higher speeds . . . less rigidity . . . more vibration are trends, not only in dancing, but in rotating machinery design. Modern designers, responsible for these undesirables, anticipate and solve them on the drafting board.

● Improvements in design and in materials have progressively decreased the ratio of weight to kilowatt output of electrical machines. As the machines have been made lighter in weight, the bases and foundations have also become lighter. This has resulted in the machines being more sensitive to vibration disturbances, for there is also less mass to absorb the energy of vibration.

The use of welded steel construction, which has almost entirely replaced cast iron, has increased the susceptibility to vibration because steel transmits vibration much more readily than cast iron. On the other hand, refinements in methods of balancing and the development of precise instruments for the measuring of vibration have led to more exacting requirements for the balance of machines. Rotors are balanced so accurately that the vibration amplitude at operating speed does not exceed one mil.

These factors have increased the importance of correcting any condition which might cause or accentuate vibration, and when undue vibration occurs in an electrical machine, the source is often hard to find. Some of the causes of vibration which are frequently encountered are discussed here.

Mechanical causes of vibration

Accurate alignment is essential to smooth operation. Couplings should be checked for radial alignment by attaching a dial indicator to one half coupling with the stem bearing on the other half coupling, and then rotating both coupling halves together and observing the indicator reading at each quarter revolution. Flexible couplings should be aligned as accurately as possible because, although they will absorb the shock caused by eccentric loading, impulses will be transmitted to the shafts and will cause vibration. This is especially true in high speed machines, and furthermore flexible couplings will wear rapidly at 3600 rpm if they are not well aligned. If shafts are not level or if bearings are not set so that the rotor "floats" on the magnetic center, there also may be axial vibration if the thrust collar of the shaft bounces against the thrust face of the guide bearing.

Mechanical power transmission means are often the cause of vibration. Gears which are inaccurately cut, worn, or are not meshing properly will set up disturbing forces. A flat belt with a splice which is thicker than the belt or a chain not uniform in pitch will cause an impulse each time the non-uniform portion passes over the pulley or sprocket. If these disturbing forces fall in step with a resonant frequency of the machine, severe vibration will result.

Oil seals, baffles or guards rubbing on the rotating member will cause a chatter, and this source of vibration can usually be detected by the local heating of the shaft. Oil seals must be set close to the shaft for the best results, but clearance should be provided for the rise and lateral movement of the shaft due to the oil film. The inner edges of the oil seals should be tapered to 1/64 inch in thickness so that, if there is contact with the shaft, the thin edge will break down to relieve the interference. Fibre oil seals should be given the same clearance as metal seals.

Vibration from bearings

The origin of vibration may be at the bearings. Any condition that causes metallic contact between the shaft and the bearing will lead to vibration. The bearing may be misaligned or pinched in the housing or may be loose in the housing. There may be high spots on the journal or bearing bushing, or the journal may be out of round. If the bearing does not have ample side clearance, enough oil may not get under the journal to maintain a complete oil film. Vibration arising from sources such as these will be accompanied by heating of the bearing. Examination of the bearing will disclose the points of interference as shiny portions of the bearing surface which should be relieved by scraping.

AT LEFT: The stator yoke of a 38,889 kva waterwheel generator on a special tilting table designed to facilitate welding.

The phenomena of oil whip is rarely encountered but may occur when the bearing length is greater than one and one-half times the diameter if bearing clearance is inadequate or if the oil is too cool or too high in viscosity. Oil whip occurs only when a shaft is running at approximately twice its critical speed. It is caused by the action of the oil film wedge which moves at half the speed of the journal and causes a shaft whirl of half the shaft rotation speed.

When a machine equipped with anti-friction bearings develops vibration, the cause may be worn or damaged bearing parts, and the balls or rollers of the bearings should be examined carefully for irregularities.

Unbalance

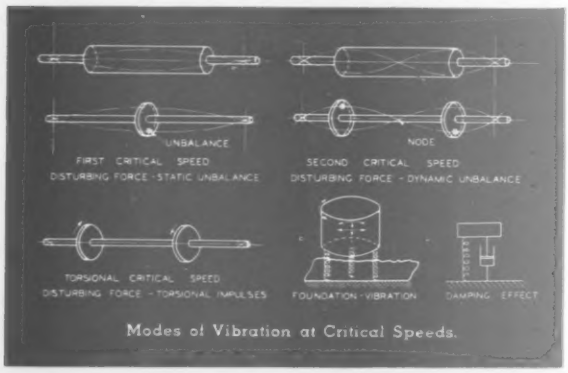
Balancing is rarely necessary in the field except when repairs or alterations have been made on the rotating element. The electrical test runs made at the factory serve to "season" the insulation so that the coils do not shift thereafter. If balance correction is required, the balancing should be done only by an experienced person.

The balance of some electrical machines changes with the temperature. This is caused by the difference in rate of expansion of the materials in the rotor. Machines which exhibit this characteristic must be balanced at the mean operating temperature and will have a slight unbalance at higher and lower temperatures.

A short circuit between turns in a field coil of an a-c motor or generator will cause vibration because of the non-uniform magnetic pull of the poles. Vibration of this nature will be noticed at the stator as well as at the bearings and will vary with the field current.

Critical speeds

The most difficult problems in vibration are encountered when the cause is resonance. Resonance occurs when the frequency of the disturbing impulses is the same as a natural frequency of the body or system. In the case of a rotating shaft the disturbing force is due to unbalance, and resonance or critical speed occurs when the frequency of rotation coincides with a natural frequency of the shaft. The amplitude of vibration at the critical speed is roughly proportional to the unbalance.



Modes of Vibration at Critical Speeds.

The shafts of the rotating elements are designed so that the operating speed does not approach the critical speed. High-speed motors and 3600 rpm turbogenerators pass through the first critical speed, but the rotors are so proportioned that the first critical speed occurs at about one-half operating speed and the second critical speed at about 40 percent above operating speed. Stator yokes are designed to have the natural frequency well above normal speed and appreciably different from the frequency of magnetic forces impressed on the stator by the rotating field.

Natural frequency hard to find

However, the natural frequency of the supporting structure, consisting of base, foundation, etc., is a matter hard to analyze and is often given little consideration. This, being a complex system, will have a number of critical frequencies in three planes. If a resonant frequency of the supporting structure coincides with the critical speed of the rotor, there will be severe vibration while the rotor is passing through that speed. If a resonant frequency coincides with the operating speed of the machine, it will be nearly impossible to have a smoothly running machine since a slight amount of unbalance will cause noticeable vibration.

The natural frequency of a machine or structure is a function of the weight and rigidity. The amplitude of vibration is limited by the damping effect which in turn depends on the mass and vibration-absorbing properties of the material. Generally, when vibration is caused by a resonant condition of the foundation, the vibration will be transmitted to the floor, to the ground, and to nearby objects. The best remedy is to add a liberal quantity of concrete, which will stiffen the structure and provide additional damping.

Another form of resonance to be avoided is that of torsional vibration. Examples where this may occur are mill drives through reduction gear, diesel engine driven generators, and reciprocating type compressor drives. If the torsional impulses resulting from gear tooth impact or piston reaction occur at the same frequency as the torsional critical frequency of the unit, severe torsional vibrations will develop which may cause a broken shaft or other failure. These units are designed to have the resonant frequency safely above that of the torsional impulses to be encountered in operation.

Alterations to be made in an existing unit, such as change of gear ratios, shaft extensions, or couplings which may affect a change of frequency, should be referred to the manufacturer for approval in order to avoid the possibility of running at a critical speed.

Vibration isolation

For the reduction of noise and transmitted vibration, isolating materials may be effectively used, particularly on smaller machines. The common isolating materials are rubber, cork, felt and steel springs, the selection being dependent on the loading and frequency of vibration.

WITH THE GREATEST OF EASE

H. N. Hayward, Associate Professor of Electrical Engineering

UNIVERSITY OF ILLINOIS • URBANA, ILLINOIS

For calculations requiring more than slide-rule accuracy, it is no longer necessary to page through voluminous "trig" tables. Now you can read functions directly to as high as five places . . . with slide-rule speed . . . on this amazing one-page table.

● This graphical table of the natural sine, cosine and tangent trigonometric functions is the same, except in form, as any table of natural functions and may be used as an ordinary trigonometric table. With an angle or one of the functions given, all the related quantities can be read directly from the table and any necessary interpolations quickly made without calculation. Unlike the ordinary trigonometric table, the degree scale is divided to tenths of a degree instead of minutes for convenience in making vector and complex quantity calculations as will be explained later, but a conversion chart is furnished (see upper right corner of chart) so that fractions of a degree may be expressed in minutes.

The degree scale adjacent to the tangent scale and those between the sine and cosine scales are identical except for the numbering, permitting the transfer from a value of one function to corresponding values of other functions without using a straightedge. One of the degree scales is numbered for angles in all four quadrants, those in the first and third quadrants increasing to the right and those in the second and fourth increasing to the left as indicated by the small arrows adjacent to the numbers, permitting the functions of any positive angle less than 360 degrees to be read directly from the table.

Vector and complex quantity calculations

This table also is useful in evaluating the absolute value of a vector or quantity expressed as a complex number, in finding the reciprocal of a complex number, and in the multiplication and division of vector and complex quantities. Since the quantities may be located in any of the four quadrants, the angular scale extends from 0 to 360 degrees. The signs of the functions in each of the four quadrants for positive angles are given in the table of "Signs of Functions" at upper left corner of chart. For negative angles, the sequence is reversed, and the order of the quadrants is 4, 3, 2, and 1 as the negative angle increases from 0 to 360 degrees. The sign of the real component of the complex number is determined by the cosine, and the j, or quadrature component by the sine, of the angle the quantity makes with the positive reference axis.

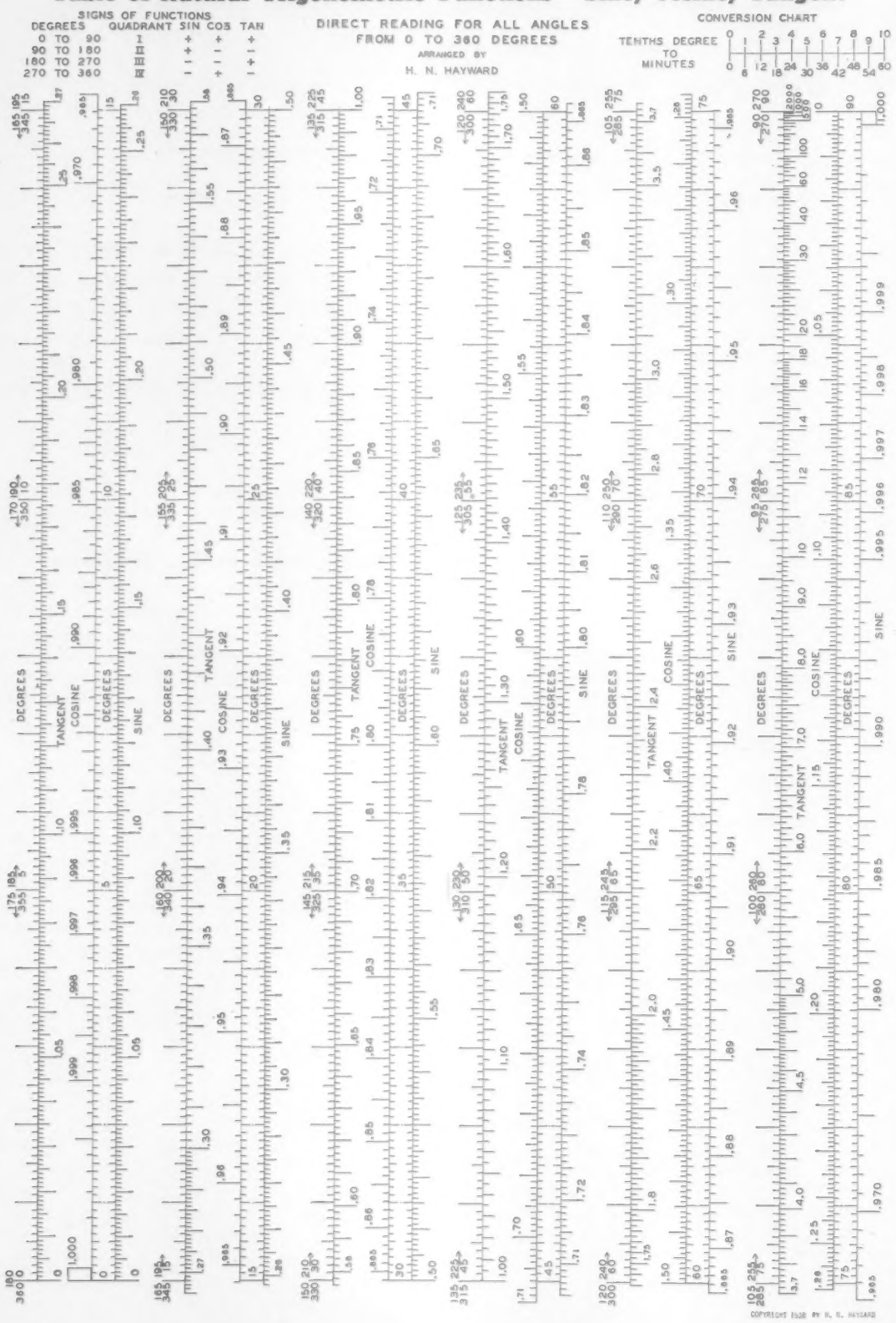
Length of a vector

1. To find the length of a vector or the absolute value M of a complex number $\overline{M}=M'+jM''$; where $M'=M\cos m$, $M''=M\sin m$ and m is the angle made by the quantity with the positive reference axis. Determine the ratio M''/M', which is tan m, by calculation. From the value of tan m, the sine, cosine and magnitude of the angle can be read directly from the table, although only the sine or cosine need be found to evaluate M. Dividing M′ by cos m or M″ by sin m will give the absolute value M of the quantity. If M′ is larger than M″, use M′/cos m, but if M″ is larger, use M″/sin m. Since the absolute value has only magnitude, the signs of the components need not be considered in this case.

The table can be used to find the absolute value of a voltage, current, impedance or admittance expressed as a complex number.

EXAMPLE: Find the value V of the voltage $\overline{V}=33.5+j67.4$. The ratio 67.4/33.5, which is tan v and equals 2.01, is calculated (a slide rule can be used to determine the ratio with sufficient accuracy in the solution of most ordinary problems). The values of the angle $v=63.55$ degrees and $\sin v=0.895$ are read from the table. The value of $V=67.4/0.895=75.3$. This compares with the usual method of finding the absolute value by taking the square root of the sum of the squares of the components.

Table of Natural Trigonometric Functions — Sine, Cosine, Tangent


SIGNS OF FUNCTIONS
DEGREES QUADRANT SIN COS TAN
0 TO 90 I + + +
90 TO 180 II + − −
180 TO 270 III − − +
270 TO 360 IV − + −
DIRECT READING FOR ALL ANGLES
FROM 0 TO 360 DEGREES
ARRANGED BY
H. N. HAYWARD
CONVERSION CHART
TENTHS DEGREE TO MINUTES
0 1 2 3 4 5 6 7 8 9 10
0 6 12 18 24 30 36 42 48 54 60
DEGREES
TANGENT
COSINE
SINE

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Reciprocal of a vector

2. The reciprocal of a vector or complex quantity is the reciprocal of the absolute value of the quantity, and the angle made by the reciprocal with the reference axis is the negative value of the original angle. To find the reciprocal of $\overline{M}=M'+jM''$, calculate the value of the ratio M''/M', which is tan m, and read the value of m and the sine and cosine from the table. Then:

$$\frac{1}{\overline{M}} = \frac{1}{\frac{M'}{\cos m}} = \frac{\cos m}{M'},$$

and

$$\frac{1}{\overline{M}} = \frac{\cos m}{M'}\,[\cos(-m)+j\sin(-m)]$$

EXAMPLE: Find the reciprocal $1/\overline{Z}$, which is the admittance $\overline{Y}$, of the impedance $\overline{Z}=2.47+j6.65$. Tan $z=6.65/2.47=2.69$. Then, from the table: cos $z=0.348$, sin $z=0.937$ and the angle $z=69.6$ degrees.

$$Y = \frac{1}{Z} = \frac{\cos z}{Z'} = \frac{0.348}{2.47}$$

$$= \frac{\sin z}{Z''} = \frac{0.937}{6.65} = 0.141$$

$$\overline{Y} = \frac{1}{\overline{Z}} = \frac{\sin z}{Z''}[\cos(-z)+j\sin(-z)]$$

$$= 0.141\,(0.348-j0.937)$$

$$= 0.0491-j0.132$$

To multiply complex numbers

3. Multiplication of vector and complex numbers involves the product of the absolute values, and the angle of the product is the sum of the angles. To multiply $\overline{M}=M'+jM''$ by $\overline{N}=N'+jN''$, calculate the ratios M''/M' and N''/N', which are tan m and tan n respectively. From these values, the two angles and their sines and cosines can be read from the table.

The absolute value of the product MN is obtained by multiplying $M'/\cos m$ by $N'/\cos n$, and the signs of the components and functions need not be considered since the absolute value has only magnitude. The angle $(m+n)$ is found by addition; then sin $(m+n)$ and cos $(m+n)$ can be read from the table. The product can be expressed as a complex quantity by multiplying the absolute value MN in turn by cos $(m+n)$ and jsin $(m+n)$. The result is:

$$MN = \frac{M'}{\cos m} \times \frac{N'}{\cos n} \text{ and } \overline{M}\overline{N} = \frac{M'}{\cos m} \times \frac{N'}{\cos n}[\cos(m+n)+j\sin(m+n)].$$

EXAMPLE: A series impedance consisting of 21.2 ohms resistance and 7.45 ohms inductive reactance (at some given frequency) carries the current $\overline{I}=-1.23-j4.76$, and it is desired to find the complex expression for the impressed voltage. The complex expression for the given impedance is $\overline{Z}=21.2+j7.45$. Tan $z=7.45/21.2=0.351$ and tan $i=-4.76/-1.23=3.87$. The angle z is in the first quadrant, because both components are positive (resistance always has a positive value, and the sign of the j component for inductive reactance is positive since there must be a component of the impressed voltage 90 degrees ahead of the current in inductive circuits). The angle i is in the third quadrant because both components are negative.

The angles and their sines or cosines can be read from the table, and are:

$z=19.35$ degrees cos $z=0.943$

$i=255.5$ degrees sin $i=-0.968$

By calculation, the angle $(z+i)=19.35+255.5=274.85$ degrees is found, and the functions of this angle are read from the table:

$\cos(z+i)=0.0845$, and $\sin(z+i)=-0.996$

The absolute value of the voltage is $V=IZ=$

$$\frac{21.2}{0.943} \times \frac{4.76}{0.968} = 110.5.$$

The complex value is $\overline{V}=IZ\,[\cos(z+i)+j\sin(z+i)]$ and $\overline{V}=110.5\,(0.0845-j0.996)=9.34-j110$.

To divide complex numbers

4. In dividing vector and complex quantities, the quotient is the ratio of the absolute values, and the angle of the quotient is the angle of the dividend minus the angle of the divisor. To divide $\overline{M}=M'+jM''$ by $\overline{N}=N'+jN''$, calculate the ratios M''/M' and N''/N', which are tan m and tan n respectively; then read the angles, sines or cosines from the table. The absolute value of the quotient is:

$$\frac{M}{N} = \frac{M'/\cos m}{N'/\cos n} = \frac{M'}{\cos m} \times \frac{\cos n}{N'}$$

The angle of the quotient is $(m-n)$ and is found by calculation; then $\cos(m-n)$ and $\sin(m-n)$ are read from the table. In complex form, the quotient is:

$$\frac{\overline{M}}{\overline{N}} = \frac{M'}{\cos m} \times \frac{\cos n}{N'}[\cos(m-n)+j\sin(m-n)].$$

Attention might be called to a relationship which should be evident — that the quotient is the product of the dividend and the reciprocal of the divisor.

EXAMPLE: To find the equivalent impedance of a circuit if the impressed voltage is $\overline{V}=-80.5+j78.5$ and the current is $\overline{I}=-2.35-j1.75$. By calculation, tan $v=78.5/-80.5=-0.975$, and tan $i=-1.75/-2.35=0.745$. The angle v is in the second quadrant, and the angle i is in the third. From the table:

$v=135.7$ degrees cos $v=-0.716$

$i=216.7$ degrees cos $i=-0.802$

By calculation, the ange $(v-i)=135.7-216.7=-81.0$ degrees.

From the table: $\cos(v-i)=0.157$ and $\sin(v-i)=-0.988$.

The absolute value of the impedance is:

$$Z=\frac{V}{I}=\frac{80.5}{0.716}\times\frac{0.802}{2.35}=38.4 \text{ ohms}$$

The complex expression for this impedance is:

$$\bar{Z}=38.4\,(0.157-j0.988)=6.03-j37.9$$

This equivalent series impedance contains 6.03 ohms of resistance, and as the sign of the j or quadrature component is negative, the 37.9 ohms of reactance is capacitive. This relationship is apparent on inspection since the current vector is in the third quadrant and the voltage vector in the second. A leading current can result only in a capacitive circuit which will require a component of the impressed voltage to lag the current by 90 degrees, and this results only if the sign of the j associated with the reactance term in the impedance is negative.

Addition and subtraction, change in form

5. Quantities in complex form can be combined readily by addition or subtraction by taking the sum or difference of the like components. If originally expressed in polar or other form, as may be the case in some alternating-current problems, a quantity can be converted to complex form by using the table to find the values and signs of the sine and cosine of the angle made by the quantity with the positive reference axis. Multiplying the length of the vector by the cosine of the angle gives the first term, and multiplying by j times the sine of the angle gives the second term of the complex number representing the vector quantity.

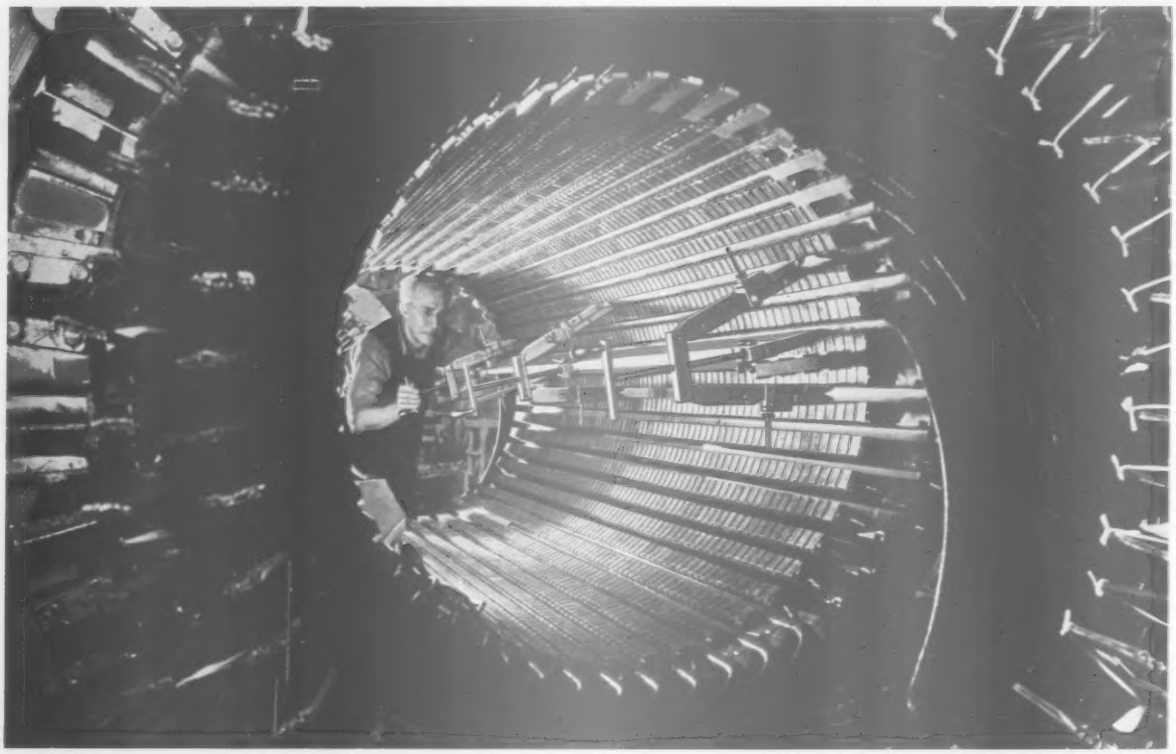
EXAMPLE: To find the complex expression for a voltage of 100 volts located at an angle of 105 degrees with the positive reference axis. From the table, $\cos v=-0.259$ and $\sin v=0.966$. Then, $\bar{V}=100\,(-0.259+j0.966)=-25.9+j96.6$.

Other applications

6. The table can be used in connection with many of the calculations for alternating-current circuits involving real power, reactive power, apparent power, power factor, reactive factor and other quantities ordinarily used in circuit analysis.

A simple example will serve to illustrate one of these applications. If the power factor (which is the cosine of the angle between the voltage and current vectors or waves in a single phase system but may be otherwise defined in a polyphase system) is given and the value of the corresponding reactive factor is desired, it can be found directly from the table by reading the value on the sine scale that corresponds to the given power factor on the cosine scale.

BELOW: Winding the stator of a 25,000 kw, 14,400 volt, 3600 rpm generator for a midwestern system's generating station.



0.000 000 000 000 000 000 000 000 0009 GRAMS

O. Keller

RECTIFIER DIVISION • ALLIS-CHALMERS MANUFACTURING COMPANY

That's the calculated weight of an electron. But if enough of these impinge on a rectifier anode, they can cause an internal short circuit . . . a phenomenon known as rectifier "backfire."

● The ear-splitting crack of a backfiring gasoline engine is well known. What is not so well known is the fact that a mercury arc rectifier, although it does not burn gasoline — nor any fuel for that matter — may also be subject to a phenomenon which is sometimes also called a backfire.

Strictly speaking, a more accurate designation of such an occurrence is an "arc back." As has been explained before in these columns, a rectifier anode normally receives only electrons which are sent out to it from the mercury cathode. These electrons are so extremely light in weight, weighing only 0.000 000 000 000 000 000 000 0009 grams, that even though trillions of them impinge on the surface of the anode, they do not heat it enough to cause thermal emission.

Possible causes of backfires

If, for some reason or other, a droplet of condensed mercury comes to rest on an anode, the droplet may start to give off electrons. If an impurity exists on the surface of an anode, or if some foreign material, which may evaporate and be deposited on an anode, is present in a rectifier, that impurity may also act as an electron-emitting cathode spot during the inverse-voltage half cycle; that is, the half cycle during which the voltage of a particular anode is negative with respect to the cathode. Such an occurrence is then called a backfire or arc back. The latter term was coined because in such a case the current through that anode which is no longer rectifying flows "backward" with respect to its usual direction.

Backfires can also occur if a rectifier is operated at unusually low temperature. Still another potential cause of backfires lies in the possibility that a rectifier may be excessively overloaded for so long a time that even its ordinarily marked insensitivity to overloads is exceeded. Under such conditions one or more anodes may become locally overheated so that they start to emit electrons even if no impurities exist on their surfaces.

If any of these conditions exist, then under the influence of the electric field existing during the half-cycle when the voltage of an anode is negative with respect to the cathode, a backfire may occur. Obviously, every precaution is taken to keep the number of backfires to a minimum — beginning with the design of the rectifier and extending through the manufacturing processes. Some of the major precautions that are taken to prevent excessive backfiring include the provision of adequate cooling of the various internal parts of a rectifier to prevent condensation of mercury on the anode structures, the design of these parts to withstand even repeated arc backs without damage, the insistence on materials of extremely high purity, and scrupulous cleanliness in assembling the rectifiers. To these must be added care on the part of the user to prevent excessive overloads of long duration.

In general it may be said that rectifiers are more susceptible to arc backs at the higher d-c voltages; at voltages up to approximately 300 volts direct current, backfires are rare.

The phenomenon of rectification is, of course, the same whether the rectifier consists of a number of single-anode tanks or of a multiple-anode tank. Consequently the possibility of backfires exists for both types of rectifiers if the conditions indicated above occur.

Effects of backfires

When a backfire does occur, mercury ions, which are many thousand times heavier than the electrons, will begin to bombard the surface of the "faulty" anode, heating it still further. Within a very short time, not only will that anode develop a cathode spot on its surface, which will in normal conditions develop only on the surface of the mercury pool, but the other anodes, whether in the same tank or in separate

single-anode tanks, will start to feed their current into this backfiring anode.

Further complications arise if the rectifier is operating in parallel with other sources of direct current, or if it happens to be connected to a load which has a counter emf. In either of these cases the other d-c machines operating in parallel with it, or the back emf from the load, will feed current into the backfire arc. This heats the faulty anode still more, causing its cathode spot to become larger and hotter and establishing a vicious circle until the reverse current may attain a peak value of up to 30 times the normal peak forward current.

Since a backfire is virtually an internal short-circuit in the rectifier station, the current will rise to a value limited only by the electrical characteristics of the rectifier itself and its associated transformer. Fortunately, as the current passing through a rectifier reaches very high values, the voltage drop through the arc increases, and this tends to limit the short-circuit current. Another limiting factor is, of course, the reactance of the transformer windings. The reason that the arc drop increases at very high currents is that the concentration of the electrons in the arc path is then appreciably greater. As a result a higher resistance is offered to the flow of the current, and consequently the value of the short-circuit current is limited.

Backfires set up severe stresses in rectifier transformers, and the power should be tripped off as soon as possible. As a precautionary measure, both the windings themselves and also the internal connections of rectifier transformers are well braced to withstand these stresses.

One way to interrupt an arc back is to open the d-c and a-c breakers of the rectifier unit. The one breaker will prevent the flow of reverse direct current, and the other will stop the good anodes from feeding into the backfire. However, this method of interrupting a backfire will take a number of cycles.

A much quicker and more ingenious way of interrupting the a-c component of the backfire current is by means of the electrically energized grids which most modern rectifiers have located in the path of the arc, a short distance below each individual anode. By the immediate application of a negative voltage to all the grids of a rectifier at the instant that a backfire occurs, which can readily be done by means of modern high-speed relays, or even more rapidly by means of small auxiliary vacuum tubes, the backfire, instead of persisting for several cycles, can be interrupted or completely extinguished within a fraction of a cycle. Backfires in single-anode rectifiers can also be snuffed out by interrupting the ignition or the excitation current, depending upon whether they are of the intermittently excited Ignitron type or of the continuously excited Excitron type.

Obviously any of these methods of backfire interruption can advantageously be combined in various ways with the older type of protection using the d-c and a-c circuit breakers.

Question—A warehouse gets power for 250 volt d-c cranes, hoists, and elevators from an antiquated steam-engine-driven generator. This generating equipment shows signs of failing, and expensive repairs will soon be required. The purchase of a-c power from the local utility and installation of a 300 kw motor-generator set or mercury arc rectifier is therefore being considered. What advantage, if any, would a rectifier unit show over an m-g set? The average load factor is about 23 percent over a 10 hour day, 300 day year working period. H. M. K.

Answer—The rectifier unit, with slightly higher first cost, has the advantage of relatively high over-all efficiency which varies only little over its normal operating range. On full load the difference in efficiency of a rectifier and equivalent m-g set is only a fraction of one percent, but this difference becomes much greater at smaller loads. For the 300 kw rating and 23 percent load factor the efficiency would be about 85.5 percent for the rectifier, but only 71 percent for the m-g set. This difference represents an average saving in conversion losses of about 16.5 kw, which for the given working year of this plant amounts to nearly 50,000 kwh. At one cent per kwh power cost, a saving of about $500 per year could thus be secured by using a rectifier unit. Capitalized at 10 percent, this annual power saving represents a sum of $5000, which would fully justify the higher first cost of a rectifier unit.

Noiseless and vibrationless operation, smaller installation and maintenance costs are other advantages which favor rectifiers.

Question—We have space on our turbine floor that is three feet too short for straight removal of the rotor from the stator of a 7500 kw turbo-alternator that we shall have to install soon. Is any special unit available that will save us making expensive building alterations? F. A. B.

Answer—A simple means of removing turbo-generator rotors from the turbine end of the machine is available on some of the new machines. This removal is accomplished by raising the coupling end of the generator upward, using a special pivot block at the outboard end, and then, by means of a jack and a few special blocks and rolls, removing the rotor over the turbine end.

"What's the Answer?" is conducted for the benefit of readers of ELECTRICAL REVIEW who have questions on central station, industrial or power plant equipment. Send all questions to the Editors of ELECTRICAL REVIEW.

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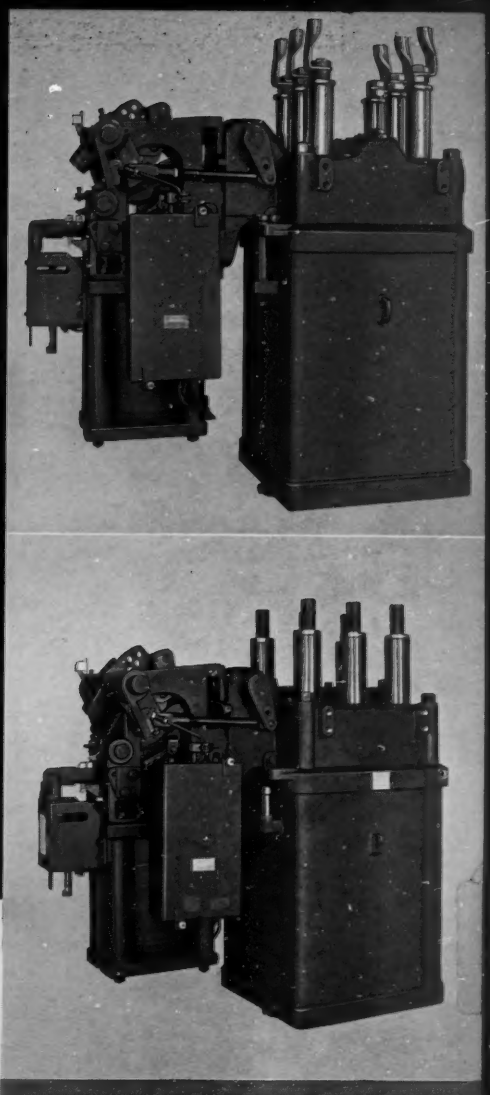

SIMPLIFY YOUR BUS AND FEEDER connections with the bushing arrangement that fits your layout. The DZ-40 (above) is the conventional type, while the poles of the KDZ-40 (below) are arranged perpendicular to the face of the breaker.

When a switchgear project is under way . . . when economy is essential . . . that's when adaptable oil circuit breakers that simplify connections . . . save time, space, and materials . . . are a boon and a blessing.

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ASK YOURSELF THESE FIVE QUESTIONS!

Then Decide if You're Buying the Best Regulators for the Job to be Done. Here are the Facts on the Five-Way Savings You Get with the Allis-Chalmers 5/8% Step DFR Feeder Voltage Regulator!

1 **HOW CLOSELY DO THEY REGULATE?** Allis-Chalmers' DFR . . . with "Feather-Touch" Control . . . permits band width settings within ± ⅝ of 1%.

2 **DO THEY INCREASE WATTLESS CURRENT?** Actually excitation current of the DFR is *only a fraction* of that required by older types of regulators. That means you don't have to install costly static capacitors to release system capacity for pay loads.

3 **ARE THEIR LOSSES HIGH?** No . . . for at the neutral position, the copper loss of the Allis-Chalmers DFR approaches zero. You get more efficient operation in the range where the highest percentage of operations occur.

4 **ARE THEY TOO NOISY FOR URBAN STATIONS?** Quiet-operating DFRs . . . with no air gap, fringing flux, or clatter of relays . . . make no more noise than a distribution transformer of equivalent size.

5 **WHAT ABOUT MAINTENANCE EXPENSE?** No holding or braking devices are necessary on the DFR. And complete oil immersion of all moving parts eliminates the need for other lubrication. What's more, in the seven years Allis-Chalmers ⅝% Step Regulators have been in service, *not a single contact has ever been replaced due to deterioration under normal operation!*

For all the answers on the famous five-way savings of Allis-Chalmers ⅝% Step DFR Regulators, call the district office near you. Or write direct to Allis-Chalmers, Milwaukee, for your copy of our new bulletin B-6065. A 1312

THESE SIX 72 KVA, 2400 VOLT ALLIS-Chalmers ⅝% Step DFR Regulators on a northwestern system give the right answers to the five fundamental questions of regulator economy.

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5. MINIMUM MAINTENANCE COSTS!

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